THE ENGINEERS' DIGEST

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The Blue Pages

As a result of the publication of The Blue Pages for the first time in our May issue, we have received a number of enquiries for further information on items briefly reviewed. It appears, therefore, that this new section has stimulated interest among our readers and has been generally well received. In support of this view, we take the opportunity of reproducing below just two of the numerous letters we have received :—

DEAR SIR,

We wish to compliment you on the introduction of The Blue Pages in the May issue of "The Engineers' Digest." These brief but informative items are extremely helpful and will go far towards meeting the difficult situation which has arisen, due to the large increase in the volume of technical matter which has occurred since pre-war days.

We are particularly interested in the following item . . . etc., etc.

H. R. HAERLE,
Technical Manager,
THE HYMATIC ENGINEERING COMPANY LTD.

DEAR SIR,

As one of the engineers to whom you refer in your Editorial for May, 1950, with such sympathy and understanding, may I say how I welcome the addition to your journal of The Blue Pages, which I think are going to prove a most valuable asset to your records, and a high recommendation for your journal.

May I suggest that there are two things which would add materially to the value of these Blue Pages, with very little added expense to your journal.

The first is the provision on, say, a quarterly basis, of a progressive index. The Blue Pages are admirably planned so as to be extracted and filed separately, but I am sure you will agree with me that their value as a work of reference will be seriously impaired unless you can provide an adequate index.

My second suggestion is that where the subject matter of any paragraph in The Blue Pages has been dealt with in greater detail, reference to the respective issue might be appended at the foot of the paragraph and this would save a great deal of time and correspondence on the part of both yourself and your readers.

E. L. FORGE,
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In publishing these letters it is not our intention to draw praise, but rather to encourage frank criticism. This should enable us to shape our future policy in accordance with our readers' comments.

Change Wheel Gearing

WE are publishing in this issue the final instalment of the series of articles on Change Wheel Gearing. The last chapter "Gearing of Machine Tools," commenced last month, leads from theoretical considerations to the requirements of practice. It has been shown that cutting standard threads in a lathe does not involve any problems, nor does the cutting of metric threads if a translating gear 127 is available; however, the author demonstrates that metric threads can also be cut satisfactorily by using only standard gears. Worm threads, although standardised, are usually considered as odd threads, and the table published in our May issue should cover any requirements.

The milling machine, in this respect, is characterised by a wide and stepless range of requirements, but in most cases it is sufficient to choose a nearby value from a table of ratios obtainable by a standard set of change wheels.

The hobbing machine, however, is representative of a type of machine for which an unlimited number of gear combinations may be required in order to keep within small tolerances; therefore, tabulating is not practicable.

We have received a number of requests for reprints of this article in booklet form. It will be appreciated that such requests can only be met at a reasonable cost if there is a sufficiently wide demand. Will readers be good enough, therefore, to indicate their requirements to the Editor.

Radioisotopes

A few years ago it was generally assumed that atomic power stations would constitute the first and most important peace-time application of atomic energy. This view can no longer be upheld, because the ever-increasing use of radioisotopes in research has won for these materials the honour of being the first constructive atomic energy development. Whilst naturally radioactive isotopes (e.g., radium) have been used in the past in the medical field, the "manufacture" of artificially radioactive isotopes has presented industry with new tools of research, the importance of which can hardly be exaggerated. Nearly all elements can now be made radioactive by bombardment in particle accelerators such as the cyclotron and betatron, or in atomic piles. Space does not permit of listing the various uses made of these new materials in recent years or of speculating on their future possibilities, and interested readers are referred to an article recently published in these pages.* It is only natural

Concluded on page 212.

**The Engineers' Digest*, April, 1950, pp. 111-114.

U.S.A.

Metals and Refractories Combined in High-Temperature Structural Parts

By J. B. CAMPBELL. (From *Materials & Methods*, Vol. 31, No. 5, May, 1950, pp. 59-63, 2 illustrations.)

An up-to-date summary and objective appraisal of metal-ceramics. These materials have a wide scope of application in the gas turbine and other fields where high refractory qualities combined with some ductility and resistance to thermal shock are required.

THE growing importance of rockets and jet aircraft in both peace and war has raised an urgent materials problem. Essentially, the problem is one of developing structural materials which can withstand service temperatures in the range from 1800 to 2400° F and possibly even higher. Operating temperatures in this range would make possible tremendous improvements in thermal efficiency and, consequently, in the specific fuel consumption of gas turbines.

High-temperature alloys now used for gas turbine applications are not expected to extend the practical temperature limit beyond 1800° F, although use of air or liquid cooling appears to offer some promise for certain applications.

Early in the last war ceramic coatings were applied to low-carbon steels for high temperature use. Since the war there has been much interest in the possible use of structural ceramics for gas turbine components. Ceramics have perfect oxidation resistance and retain a high proportion of their room-temperature strength at high temperatures. However, they have almost no resistance to cracking caused by the thermal shock encountered in gas turbine operation.

Because of this important limitation, it was natural that attention should turn next to the development of metal-refractory combinations possessing some ductility and thermal-shock resistance, in addition to high refractory qualities. Most of these new materials are still very much in the early stages of development, where any available information remains on a somewhat theoretical level.

The so-called " cermets " can be described broadly as refractory metallic compounds combined with metals and fabricated primarily by powder metallurgy methods. More specifically, the compounds of most interest are oxides, borides, carbides, nitrides and silicides; but the limited amount of information available on nitrides and silicides makes it advisable to confine subsequent discussion to the first three groups. The most promising combinations at the present time appear to be aluminium oxide (alumina) with iron or chromium, zirconium boride with nickel, boron carbide with iron, and titanium carbide with cobalt or nickel.

These combinations are generally hard and brittle at room temperatures; many can be machined only with diamond tools. In density, high-temperature strength, oxidation resistance and thermal-shock resistance, they fall somewhere between the constituent metal and the refractory body. Furthermore, these properties can be varied widely by adjusting the ratio of the metallic and non-metallic phases, a process made fairly simple by powder metallurgy techniques. There is considerable speculation and disagreement on the bonding mechanisms involved in these combinations. It is clear, however, that the result is a group of materials having both metallic and non-metallic properties.

The three principal groups to be discussed in this article can be classified as oxide-metal, boride-metal and carbide-metal combinations. Terms such as " cermets " and " metal-ceramics," used to encourage anxious designers, might better be applied only to oxide-metals which are, in fact, combinations of ceramics and metals. If a general term for these new materials is necessary, use of " metalloid combinations " might be more acceptable than extending the meaning of " ceramic " to include all materials which are neither metallic nor organic in nature.

OXIDE-METAL COMBINATIONS

First attempts to use oxide-metal combinations for gas turbine blades are believed to have been made in Germany during the war. The Germans developed several compositions of alumina and iron which they called " Dug." Results of their experimentation have been verified in the intervening years, and much additional work has been done in the U.S.A. on these and similar combinations.

Alumina itself is one of the most attractive ceramics from an engineering viewpoint. It has a tensile strength of about 38,000 psi at room temperature; this value drops only slightly at temperatures up to 1830° F and, at 2200° F, tensile strength is still 20,000 psi. Compressive strength of alumina approaches 450,000 psi at room temperature, falling to 70,000 psi at 2200° F. Despite the high strength and oxidation resistance which this ceramic possesses at elevated temperatures, however, the material is extremely brittle and quite susceptible to thermal shock.

Addition of a metal such as iron to this ceramic produces, in effect, a compromise material. The high-temperature strength and oxidation resistance of the ceramic are reduced, but its ductility and thermal-shock resistance are measurably increased. An alumina-iron combination containing about 60 per cent iron is approximately half as strong as alumina alone. Specimens containing at least 30 per cent iron, on the other hand, can be heated to 1470° F and quenched in water or cold air without injury. Thermal conductivity of alumina-iron mixtures increases tremendously when iron content exceeds 50 per cent; such high conductivity often raises special problems, particularly in connection with turbine blades. The optimum amount of iron in alumina-iron materials is believed to lie between 40 and 50 per cent.

In general, standard powder metallurgy techniques are used in the fabrication of these oxide-metal materials. The metal and oxide grains, often temporarily bonded by wax, are milled together until optimum particle size is obtained. The mixture is then pressed in moulds at pressures ranging from 10,000 to 100,000 psi, and the compact is sintered at temperatures from 2500 to 3000° F under carefully controlled atmospheres.

The exact mechanism of bonding is open to considerable doubt. Recent work at Ohio State University has shown that, although metals have no inherent tendency to wet alumina at temperatures below 3000° F, wetting and adhesion are developed as a result of combination between the alumina and the oxides of the various metal additions. This suggests that, rather than the highly reducing atmospheres first employed in sintering, it would be advantageous to use atmospheres of controlled oxidising intensity; and, in fact, good results have been obtained by pre-oxidizing the metal powder surface and using a nearly neutral atmosphere in firing.

The most desirable additions appear to be those metals which have oxides of the same crystal form and nearly the same lattice parameters as the ceramic oxide and which form a continuous series of solid solutions with it. Retention of metallic properties by the sintered material, however, indicates that the metal consumed in the bonding phase must be a relatively small proportion of the metallic addition.

Other ceramics now being studied are beryllium oxide and zirconium oxide. Metallic additions being tested include cobalt, nickel, aluminium, beryllium, zirconium, chromium and copper. One combination developed at Ohio State University which shows particular promise contains 70 alumina and 30 per cent chromium.

METAL-RICH OXIDE-METALS

Although oxide-metal investigations have proceeded from both ends of the sacle, the only commercially available material of the oxide-metal type is Metamic LT-1. Its composition is 70 chromium and 30 per cent alumina.

Metamic LT-1 is strong, but brittle enough to break if dropped on a concrete floor. When it fails under stress, the fracture is completely brittle except at temperatures over about 2500° F or under prolonged stress above 1800° F. The material is also fairly sensitive to thermal shock, though much superior to most ceramics in this respect.

Tensile strength of LT-1 is about 17,500 psi at 1800° F, 7000 psi at 2200° F, and somewhat higher than 3000 psi at 2400° F. In addition to retention of fairly good strength properties in this range, LT-1 has particularly good resistance to oxidation in air at temperatures up to 2200° F and resistance to combustion gases up to 2900° F.

At the present time, Metamic parts up to 2-in. dia. by 18 in. long or 3-in. dia. by 3 in. long can be produced, with dimensions held within $\pm$ 2 per cent. A certain amount of warping and distortion must be expected, however, and where close tolerances are required, allowance must be made for finish grinding with abrasive wheels.

Grade LT-1 can be machined with tungsten carbide tools or, more slowly, with high-speed steel tools. A number of joining techniques are available; they include mechanical threaded joints, special Metamic screws and bolts, pressure welding and shrink-fitted joints. LT-1 can also be copper-brazed to steel. In some cases, complex shapes can be produced by joining subassemblies during the fabrication process. No fusion welding techniques have been developed so far.

The fields of application being considered for the Metamics are illustrated best by a representative list of parts which have been slip-cast: thermocouple protection tubes; tubes for injecting gases into molten metals; split moulds for permanent-mould casting of alloy rods; high-intensity burner nozzles; sand-blast nozzles; deflection plates for molten slag; bolts for high-temperature apparatus; high-temperature rack and roller pinions; and small calcining vessels.

In addition, LT-1 has been tested in several parts of ram jets, including the Venturi-type nozzle, the flame holders and thermocouple tubes, where gas temperatures of 3000° F are encountered. The material is also being tested for turbo-supercharger blades and gas turbine nozzles. Although its high metallic content would suggest insufficient strength at these temperatures, early reports on test results indicate that Metamic LT-1 holds some promise for such applications.

BORIDE-METAL COMBINATIONS

Research in the field of boride-metal combinations is not nearly so far advanced.

Earlier studies had shown the desirability of obtaining materials similar to cemented carbides in their refractory properties and high moduli of rigidity, but superior to the carbides in resistance to corrosion in oxidising atmospheres. A logical starting point for such research was chromium boride. Although chromium boride, sintered with a metallic binder, was ultimately found unsuitable, chiefly because of the appearance of a liquid phase at 1900° F, some of the results of this investigation have an important bearing on the future of boride-metal combinations.

Both 70 per cent nickel—30 per cent copper and 60 per cent nickel—40 per cent chromium produced good bonds in chromium boride, but the most effective binder was commercially pure nickel. Optimum properties were secured for a composition consisting of 85 chromium boride and 15 per cent nickel binder.

Attempts to cold-press compacts of powdered chromium boride and binder were unsuccessful when the boride content exceeded 75 per cent. Hot pressing at temperatures high enough to melt the binder produced dense bodies having good physical properties. In hot pressing, a sufficiently high current is passed through the powder mixture in a graphite die to raise the temperature of die and mixture above 2700° F in 1 to 2 min. When the temperature is reached at which pressing is to occur, the current is stopped, and pressing accomplished by hydraulic means. The carbonaceous atmosphere within the die and the short time involved make it possible to avoid oxidation without providing a special atmosphere.

Since these tests were carried out, it has been announced that a zirconium boride compound had been developed which is said to have survived higher temperatures than any other material. The fact that zirconium boride alone has a melting point about 2000° F higher than chromium boride and 1700° F above that of alumina indicates that high refractory properties can be expected. The actual composition of this material may approximate 85 per cent zirconium boride and 15 per cent nickel.

CEMENTED CARBIDES

Cemented carbides as such need little introduction here. Their usefulness as tool material has long been recognised. Recent work at Kennametal, Inc., has resulted in the development of a whole series of cemented titanium carbides, fabricated by powder metallurgy and possessing high strength and oxidation resistance. In these compounds, tremendous improvement in oxidation resistance has been achieved by replacing part of the titanium carbide by the high-melting tantalum and columbium carbides. The reason for the marked effects of such additions is not known.

The auxiliary metals used in these titanium carbide compositions are cobalt and nickel, the nickel being used at present only where special chemical resistance is needed. These two binders offer equal oxidation resistance, but cobalt seems to provide the better high-temperature strength.

Many of the properties of the Kentanium series have yet to be determined, but a few are listed in Table I. Additional properties have been determined for some grades and give a fair indication of those to be expected from the remaining grades. Thus, the thermal expansion coefficient from 100 to 1200° F is about $4{\cdot}5 \times 10^{-6}$ per °F, thermal conductivity is about 18 Btu/hr/sq ft/ft/ °F, and room temperature compressive strength is about 450,000 psi. Both thermal and strength properties are affected by the amount of auxiliary metal; room temperature strength increases with the amount of metal binder, but high-temperature strength is adversely affected.

A long-standing difference of opinion over the bonding mechanism in cemented carbides has been extended to these higher temperature grades. Thus, it is not certain whether the cemented carbides owe their properties primarily to the carbide or to the metallic phase. It is apparent, therefore, that the exact nature of these high-temperature cemented carbides is not fully established at the present time.

Cemented titanium carbides cannot be machined after sintering, although they can be ground with diamond wheels. They are just as susceptible as tool compositions to cracking from local overheating, how-

TABLE I.—PROPERTIES AND APPLICATIONS OF KENTANIUM OXIDATION-RESISTANT GRADES.

Grade	K138A	K139A	K140A	K141A	K150A	K151A
Composition, %*	TiC, 80 Co, 20	TiC, 95 Co, 5	TiC, 90 Co, 10	TiC, 70 Co, 30	TiC, 90 Ni, 10	TiC, 80 Ni, 20
Specific Gravity	5·8	5·4	5·6	6·0	5·6	5·8
Modulus of Elasticity (Room Temp.), psi	$57·3 \times 10^6$	$51·2 \times 10^6$	$53·2 \times 10^6$	$54·3 \times 10^6$	$52·7 \times 10^6$	$56·7 \times 10^6$
Transverse Rupture Strength (Room Temp.), 1000 psi	150·0	112·0	135·0	190·0	—	150·0
Hardness, Rockwell A	89·5	93·0	91·5	87·5	—	89·0
Relative Properties :						
High Temperature Strength	Higher	Lowest	Medium	High	Medium	High
Softening Temp.	Medium	Highest	Medium	Lowest	Medium	Medium
Thermal Shock Resistance	High	Lowest	Medium	Highest	Medium	High
Applications	Hot tube spinning tool. Extrusion dies for brass or bronze. Thermocouple protection tubes.	—	Molten metal thermocouple protection tubes. Resistance heating elements for electric furnace.	Hot working dies where severe shock encountered.	Same as K140A. Also resists attack by aluminium and glass.	Same as K138A. Also resists attack by aluminium and glass.

*Titanium carbide figure includes unspecified amount of tantalum and columbium carbides.

ever, and the same precautions taken for tool compositions must be observed. These compositions cannot be brazed by ordinary methods; furthermore, the temperatures at which they operate render present brazing materials useless. Welding is impractical because of cracking. These materials can be threaded, but other methods of mechanical holding are preferred wherever possible.

Another titanium carbide mixture which may prove useful is one containing about 10 per cent molybdenum as a binder. In tests conducted by the National Advisory Committee for Aeronautics, this combination demonstrated better high-temperature strength than any other titanium carbide material. Although its oxidation resistance was much poorer than that of cobalt-cemented titanium carbide, the N.A.C.A. tests did not include materials reinforced with tantalum and columbium carbides.

Still another carbide which has undergone extensive investigation is boron carbide, of special interest because it is the hardest substance produced by man. N.A.C.A. tests have shown that a sintered mixture of 64 boron carbide and 36 per cent iron has a strength-weight ratio at 2400° F about 20 times that of 80 titanium carbide and 20 per cent cobalt, and twice that of the 90 per cent titanium carbide and 10 per cent molybdenum mixture. The specific gravity of this combination is only 3·2 compared with 5·8 for the titanium carbide material. Unfortunately, the tests also indicated that the rate of oxidation was such that a protective coating would be required for continued operation above 1600° F. Since the addition of tantalum and columbium carbides has imparted so much oxidation resistance to cemented titanium carbides, it is interesting to conjecture whether similar results might not be obtained for cemented boron carbides.

OUTLOOK FOR TOMORROW

The scope of potential applications for high-temperature materials has been indicated somewhat generally. In addition to blading, the most urgent requirements include materials for the interior of turbine engine tubes; for tailcones and tailpipes; for afterburner parts; for rocket combustion chamber liners and nozzles; for missile combustion chambers, guide vanes, reactors and warheads; for applications to supersonic aerofoils; and for other vital uses in jets, rockets and guided missiles.

Many of the metalloid combinations under development, and especially those now commercially available, have proved suitable for certain high temperature applications. It is safe to say, however, that the overall problem has not diminished appreciably. Although the use of K138A stator blades in production engines within this year has been forecast, not one of these metalloid combinations is believed suitable for use in gas turbine rotor blades at the present time. Even where the problems of strength, oxidation resistance and resistance to thermal shock have been overcome, important fabrication and cost problems remain.

Although cemented carbides appear to be the most promising of these materials for early application to gas turbine parts, the other metalloid combinations should not be overlooked. The tantalum and columbium carbides, used to add oxidation resistance to the cemented titanium carbides, are being obtained from tin extraction dross but, nevertheless, the generally critical supply of these additions must be considered in evaluating the usefulness of the cemented carbides. No such scarce alloying elements are required for the oxide-metal and boride-metal combinations. And there are many additional metallic compounds which have not yet been fully investigated.

Furthermore, the metalloid combinations fabricated by powder metallurgy cannot justifiably be considered alone, as they will have to compete with many other types of processes and materials. Other methods of combining metal and ceramic phases are being investigated, including vapour impregnation and capillary intrusion of the molten metal into prefired ceramic bodies. Another technique consists of vaporising metal and ceramic together and depositing the combination as a metalloid coating on a base material.

Much attention is being devoted to methods of producing ceramic coatings on metals, such as electrolytic methods, spraying, dipping, fusion, etc. Research is also being conducted on such materials as graphite and silicon carbide mixtures; fused alumina and silicon carbides; oxides, borides, carbides and nitrides without metal binders; carbonaceous materials with or without metallic powder additions and/or bonding materials; compounds of plaster of Paris, gypsum, graphite or carbon to provide cooling by chemical reaction; bodies of one, two and three constituent oxides; and ternary and quaternary oxide systems with complete liquid miscibility on melting.

Although there is no guarantee that metalloid combinations will prove the most effective types of high-temperature materials, enough research has been done to show that materials having the properties of both metals and non-metals can be applied under certain conditions of high temperature service. Some of them may be important engineering materials of tomorrow.

XUM

Non-Flammable Hydraulic Fluids

By C. A. H. Pollitt, M.I.E.D., A.M.I.Ae.S.

A survey of the present stage reached in the development of non-flammable hydraulic fluids for aircraft hydraulic systems.

INTRODUCTION

Manifold advantages are to be derived from the use of non-flammable hydraulic fluids, particularly for aircraft hydraulic systems and also in the lubrication of gas turbines for general industrial purposes. The fire risk due to fractured hydraulic pipes in aircraft installations has been considerably increased by the introduction of high-pressure systems of the order of 3,000 psi. In such systems a fractured pipe may discharge a fine spray of hot oil on to a still hotter surface and the vapour given off by this action often ignites autogenously. Another potential fire risk is created by a leaking hydraulic gland causing oil to drip on to the rubber insulation of a nearby electric cable. As the rubber perishes under the action of the oil, the bare cable is eventually exposed to the oil, thus causing a short-circuit.

Petroleum oil is the usual fluid medium used in hydraulic systems, but there are fundamentally divergent views as to which of the alternative fluids, that is, water-base, halogenated, and ester-base, give greater promise of complete non-flammability. Nevertheless, several non-flammable fluids have been developed, all of which have inherent limitations in that they attack synthetic rubber seals and gaskets. This is now one of the principal difficulties and is engaging the attention of manufacturers of synthetic rubbers, but with, so far, negative results.

In view of these difficulties, all the principal oil companies have conducted exhaustive researches into the compounding of suitable new fluids, including water-soluble types, ester types, silicone types, and halogen-containing types.

WATER-BASE FLUIDS

One of the first completely non-flammable hydraulic fluids to be introduced was a water-base fluid evaluated by the American Navy and known as "Hydrolube U-4." This fluid has been in use for rather more than two years, but is too expensive for general commercial usage.

The most cogent criticism of water-base fluids concerns evaporation residues; resulting from leakage, these are highly inflammable and, therefore, particularly dangerous in high-pressure systems. Magnesium corrosion is also pronounced, but it is understood that further development will enable this difficulty to be circumvented.

It is difficult to ascertain the true merit of water-base fluids in terms of low temperature viscosity. Of the two schools of opinion, both violently opposed, one defines these fluids as being inherently limited because of their high viscosity at low temperatures; the opposite view is sustained by the fact that a water-base fluid is in existence the low temperature properties of which are superior to those of current petroleum-base compounds.

While it is true that some non-flammable fluids are known to be toxic, water-base fluids are not exceptionally so. The question of toxicity has been widely misunderstood and its effects grossly exaggerated. This property is proportional to vapour pressure and the real danger only asserts itself when there are heavy vapour concentrations. Leaded petrol, carbon tetrachloride, aromatics, and solvents, are all toxic, but are used extensively and regularly in laboratories and workshops without undue risk. Although there are known precautions for countering this potential danger, these are not necessitated by the usual routine servicing of hydraulic systems.

HALOGENATED FLUIDS

These fluids are completely non-flammable and are, in fact, fire extinguishers. The California Research Corporation have produced a halogenated fluid marketed as the Standard Oil Company's RPM fluid, and this was recently described at length by Farrington, Furby, and Stokely, in a paper presented before the Society of Automotive Engineers. The following abstracts summarise the composition and properties of this fluid. The principal ingredient is a halogenated non-aromatic hydrocarbon. The halogenated ingredient is inherently stable as compared to other non-aromatic hydrogenated hydrocarbons having properties suitable for use in hydraulic systems. It was discovered at an early stage that even this material developed acidity at elevated temperatures, and considerable research and experimentation was necessary to eliminate this corrosive tendency. Perhaps the most significant achievement of the experimental work was the formulation of an inhibited fluid which was non-corrosive to light alloys even under greatly accelerated conditions of high temperature and prolonged use in 3,000-psi systems. Other additive materials necessary to depress the freezing point, reduce wear, increase the viscosity index, and decrease foaming, are embodied. The properties of this fluid are as follows:—

Table I.—Properties of RPM Non-Flammable Hydraulic Fluid.

Density at 60° F, gram/cm³	1·51
Viscosity at 210° F, Centistokes	2·95
Viscosity at 130° F, Centistokes	5·88
Viscosity at 100° F, Centistokes	8·54
Viscosity at — 40° F, Centistokes	425
Pour Point °F	—95
Low Temperature Stowage (72 hours at —65° F)	Remains fluid
Acid Number	Nil
Miscibility with Petroleum Base Fluids	Complete
Corrosion of Metals	Nil

Effect on Rubber Seals and Packings. This fluid causes excessive swelling of ordinary seals and packings, but special rubber packings are now available with swell values in the order of 20 per cent, which is generally considered satisfactory. These materials have given good results in pump tests with this fluid, and it is believed that with the availability of non-flammable fluids the development of still more suitable packing materials will be accelerated.

Compatibility with Petroleum-Base Fluids. RPM fluid is miscible in all proportions with the existing petroleum-base fluids, the properties of mixtures falling proportionately between those of the individual fluids. With the special rubber packings, up to 50 per cent dilution with petroleum-base fluids can be tolerated before rubber shrinkage occurs. Compatibility is particularly important during the change-over period from inflammable to non-flammable fluids, as experience has shown that accidental mixing is very likely to occur during the transition period.

Toxicity. The toxicity of new organic materials, especially halogenated compounds, is naturally questionable and of particular importance when used in fluids which may contact personnel. Criteria for evaluating the toxicity of materials for hydraulic systems have not been established; however, laboratory experience has indicated that with reasonable precautions, RPM fluid can be safely handled. Moreover, operators and technicians have been exposed to fumes from laboratory fire tests, and to pump tests employing open sumps and

operating at 160° F, without evidence of toxic effects. In order to determine whether phosgene is formed as a product of thermal decomposition of the RPM fluid, vapours at the surface of a 1,300° F exhaust manifold were drawn through an absorption train employing aniline. Aniline and phosgene react to form diphenyl urea, which precipitates, permitting quantitative estimation of the phosgene present. Only a trace of precipitate was formed with RPM fluid, indicating that a small amount of phosgene was formed. In a similar test in which carbon tetrachloride was used, a large amount of precipitate formed. This fluid, therefore, is considered to be much safer in this respect than carbon tetrachloride commonly used in fire extinguishers.

Viscosity. The absolute viscosity of this fluid at 130° F has been made to match the viscosity of AN-O-366 petroleum-base fluid. Although the absolute (centipoise) viscosities at 130° F for the two fluids is thus the same, the kinematic (centistoke) viscosities differ because of the wide difference in density of the two fluids. At — 40° F, RPM fluid has a viscosity of 670 centipoises, which is considerably lower than other non-flammable fluids and approaches the 412 centipoise value for typical AN-O-366 fluid. RPM fluid is, therefore, operable at very low temperatures, and the relatively small change in viscosity with change in temperature is shown by its high viscosity index. Comparative viscosities and viscosity indices of typical hydraulic fluids are shown in Table II.

TABLE II.—ABSOLUTE VISCOSITY OF TYPICAL HYDRAULIC FLUIDS.

Fluid	RPM	AN-O-366	Water Base	Ester Base
Viscosity at — 40° F, Centipoises	670	412	3090	7330
Viscosity at 130° F, Centipoises	8·6	8·3	8·4	10·2
Viscosity at 210° F, Centipoises	4·2	4·1	—	4·1
Viscosity Index (Kinematic)	205	220	—	170

Pump Tests. Successful pump tests of this fluid in a 3,000-psi hydraulic system have been carried out. In one such test, employing a Vickers PF-3911 pump, operating at 160° F, the test was terminated at 375 hours and the condition of the pump parts was at least equal to the results obtained with AN-O-366 fluid. A further test in a supercharger hydraulic drive system, employing a Vickers pump driving a second pump acting as a motor, had completed 550 hours with the pump and motor still operating and in excellent condition.

Flammability Tests. Many types of ignition and burning tests were employed during the development of this fluid. While some flammability tests are not reproducible or representative of conditions expected in service, the tests described below are believed to have a reasonable relationship to the fire hazards of aircraft.

During a spray gun test, an intimate mixture of fluid and air was sprayed through the flames of a burning rag, and whereas conventional petroleum-base fluids in this test produced a white torch of flame, the RPM fluid was unaffected and actually extinguished the fire when sprayed on the burning rag. Water-base fluids were found to be non-flammable in this test, while the ester-base fluids tested gave a small torch effect. Silicone fluids burned with the production of dense silica fumes.

The high temperature ignition test was carried out by applying a welding torch to a spray of fluid emerging at high pressure from an orifice in a hydraulic line. The apparatus employed in testing this fluid consisted essentially of a 1500-psi, aircraft hydraulic pump, reservoir, relief valve and hand-operated valve leading to a section of copper tubing having an orifice diameter of 0·014 in. near the closed end. The severity of this test was further increased by placing a two-foot length of 3-in. diameter pipe about 6 in. away from the orifice and so positioned that the spray went through the pipe. A welding torch flame or electric arc source of ignition was placed in the centre of the spray cone and between the orifice and the inlet end of the pipe. This configuration simulated a high-pressure leak within a confined space in an aircraft, together with the sources of ignition which might be present. The usual petroleum base fluids in this test produced a spectacular blast of fire some twenty feet long and, upon removal of the ignition source, the blast continued due to the presence of the pipe section. The RPM fluid would not ignite with either ignition source. Some of the ester base fluids failed to ignite with the arc source but all were ignited with the torch. Water-base fluids did not ignite with either ignition source. The electric source of ignition employed was a 15,000-volt continuous-type arc similar to that obtainable from an aircraft ignition system. This type of arc was found to be a more consistent and severe ignition source than that obtained by striking an arc with a low-voltage, high-current battery set-up.

In another test, a short section of 3-in. diameter stainless steel exhaust manifold pipe was heated to 1300° F (dark red heat). Along one side of the pipe was welded a small rod which held up the fluid and prevented it from moving down the side of the pipe. The outside surface of the pipe was sandblasted before each series of tests. Test results with this method are not easily repeatable, as the highly inflammable petroleum base fluids, the spontaneous ignition temperature of which is 480° F, often fail to ignite, depending apparently upon uncontrollable factors of surface condition and application of fluid. Ester-base fluids were found to be quite resistant to ignition, but occasionally ignited and burned brightly. The RPM fluid would not ignite on the surface of the pipe, but flickered slightly where held up at the bead.

The fresh sandblasted surface used in this manifold test did not appear to simulate the surface of an exhaust manifold in an aircraft where exposure to high temperatures and the weather would produce a coating of iron oxides and dust. It was found that the test could be made more repeatable by the initial application of a silicone fluid which burns readily, leaving behind a coating of silica dust.

ESTER-BASE FLUIDS

This range of fluids has shown great promise and exhibited excellent lubricity. Moreover, many fluid esters are commercially available, while others can be made readily available. In fire resistance, the esters range from poor to excellent, but they all show lower-volatility hydrocarbons.

The Douglas Aircraft Co. have vigorously pursued the development of a low-toxicity, stable, ester-blend fluid, and the following abstracts from a paper by D. H. Moreton, of that Company, delivered to the Society of Automotive Engineers, reveal the pertinent features of an exceptionally comprehensive programme.

Preliminary investigations were directed towards establishing the precise extent of general interest in the subject of non-flammable hydraulic fluids. Contacts were made with most of the principal petroleum research companies, the armed services, most of the leading chemical companies, and a number of independent chemical research authorities.

As a result of these investigations, a reasonable number of fluids in varying stages of development were offered for preliminary screening and test; also several of the petroleum and chemical companies expressed an interest in working on the problem, even though they had nothing to offer at that time. Opinions

were generally unanimous that a fluid of improved fire resistance could be developed in from one to five years, although an essentially completely fire-resistant fluid would probably require from five to ten years to develop, and completely evaluate, for service use.

Work was immediately started on a suitable screening and preliminary testing programme for the fluids which had been offered as either possible or probable solutions to the problem. Standard laboratory tests for viscosity, cloud and pour point, acidity, effect on elastomeric packings, flash and fire point, and autogenous ignition temperature, were selected.

Rubber swell tests were also carried on in the course of the fluid development, although the main emphasis was placed on a satisfactory fluid, it being reasonably certain that the packing problem could best be solved after the fluid composition had been established. The general trend of the programme, therefore, consisted of first determining the physical and chemical characteristics of the pure materials.

The enormous amount of data accumulated from screening tests on 78 formulations was reduced to three basic types of fluid with several reasonable formulations in each type. The first basic type was characterised by:—

(1) Relatively high viscosity at low temperature, from 100,000 to approximately 3,000 centistokes at — 30° F.
(2) Autogenous ignition temperatures in the satisfactory range of 750° F to 850° F.
(3) Excellent resistance to spray flammability, but only satisfactory resistance to hot surface ignition.

The second type exhibited the following general properties:—

(1) Excellent low-temperature viscosities ranging from approximately 3,000 to approximately 850 centistokes at — 30° F.
(2) Autogenous ignition temperatures from 800° F to 1,000° F.
(3) Satisfactory resistance to spray flammability and from satisfactory to good resistance to hot surface ignition.

The third type was characterised by:—

(1) Moderately good low temperature viscosities ranging from approximately 5100 to approximately 2200 centistokes at — 30° F.
(2) Very high autogenous ignition temperatures varying from 1030° F to 1230° F.
(3) Good spray flammability resistance and excellent resistance to hot surface ignition.

The third of these three types was the one selected for complete development and the final derivative, known as DMX-8, performed excellently for 450 hours.

CONCLUSIONS

From the foregoing, necessarily brief, examination of water base, halogenated, and ester-base fluids, some indication can be gained of the enormity of the project of developing an entirely non-flammable hydraulic fluid. To this it may be added that no unanimity exists as to the desirable properties of such fluids, apart from their essential non-flammability.

In the opinion of the author, there is greater justification for the further development of less inflammable lubricating oils, since some of these already produced are, in fact, suitable for use in hydraulic systems and are characterised by high viscosity indices and low pour points.

SWEDEN

The Use of Transductor Regulators with Booster Exciters

By S. E. HEDSTRÖM. (From *Asea Journal*, Vol. 23, No. 2, February, 1950, pp. 23-30, 12 illustrations.)

A new and effective method of high-speed voltage control for synchronous machines is the employment of a transductor, a regulator which is continuous in operation and devoid of contacts and moving parts.

AUTOMATIC voltage control of synchronous machines is mainly required to maintain constant system voltage and ensure an efficient distribution of the reactive load, as well as increase the synchronising effort and thus raise the transmission capacity and stability limit of the power network.

Although the first two requirements are easy to fulfil with comparatively simple regulators used as automatic field rheostats, the speed of regulation, which is of decisive importance for improving network stability, makes it necessary to resort to more advanced control systems.

As a result of development work carried out in recent years, the Asea control system incorporating a booster exciter has been further improved with the introduction of a static transductor type regulator which has the advantage of requiring no maintenance.

THE ASEA CONTROL SYSTEM WITH A BOOSTER EXCITER

The control system comprises three main units: the exciter *M*, the booster exciter *SM*, and the regulator *R*, as shown in Fig. 1. The booster exciter, controlled by the regulator, is a separately driven generator connected in the field circuit of the exciter *M*, which provides its own field current.

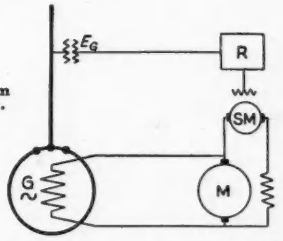


Fig. 1.
Elementary diagram of control system.

For high-speed regulation, the exciter must be able to supply at least temporarily an amount of power considerably in excess of that required for stable running conditions. Fig. 2 gives the excitation curve of the exciter. By suitable choice of the field resistance, the straight portion of the curve will coincide with the normal load range, within which the exciter will supply its own excitation current at all exciter voltages. No booster exciter voltage or regulator current is then required. If the regulated voltage varies, however, by about 1 per cent or more from the voltage setting on the regulator, the latter will supply maximum correcting excitation current to the booster exciter,

XUM

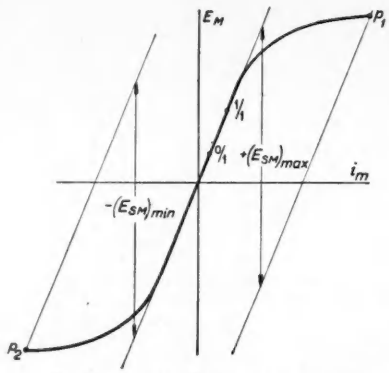


Fig. 2. **Magnetisation curve of exciter.**
Points 0/1 and 1/1 denote the requisite generator excitation at no load and full load respectively.

which will tend to force the exciter voltage towards either of the limiting values p_1 or p_2.

With this control system the rate of change dE_M/dt of the exciter voltage remains constant over a very wide range:

$$dE_M/dt = E_{SM\ max}/T_M,$$

T_M being the time constant of the exciter. This also applies for negative excitation, in cases where generators and synchronous condensers may be required with a heavy capacitive load. In practice, the rate of change determined by the above equation is limited by the fact that $E_{SM\ max}$ must not exceed a certain value, and T_M cannot be reduced beyond a certain point because of the power required. The regulator equipment is easily adaptable to the control requirements and a variation within wide limits is obtained by varying the maximum boost voltage.

In some cases, a series winding can be fitted to the exciter to improve still further the control system. The field of the exciter is then influenced also by the d.c. component induced in the excitation circuit of the synchronous machine by a transient change in the generator current.

THE TRANSDUCTOR REGULATOR

The basic diagram of a transductor regulator is shown in Fig. 3. The transductor T is connected in

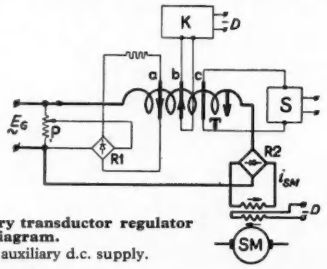


Fig. 3. **Elementary transductor regulator diagram.**
D denotes an auxiliary d.c. supply.

series with the rectifier R_2, and the generator voltage E_G is applied across these elements. The rectifier output i_{SM} is fed to one of the two excitation windings in the booster exciter. As the transductor is self-excited (this is denoted by the arrow on the right of the T in Fig. 3), it has a high sensitivity. The slightest change in the controlling ampere-turns, i.e., in the d.c. current through the control windings a, b, or c, will cause the transductor to go through its entire working range. The relative "impedance" of the transductor, which varies between a very low and a very high value, determines the working range in regard to current from the rectifier R_2. The resultant controlling ampere-turns are very nearly zero, and this determines the arrangement of the control windings and the regulator characteristics. The ampere-turns due to winding a (which carries a d.c. current proportional to the alternating generator voltage) are counteracted by the constant ampere-turns of winding b, which is energised by the constant-current device K. Disregarding winding c for the time being, it is seen that the transductor comes into operation when the ampere-turns in a and b are approximately equal.

As the regulator output is derived from a dry-plate rectifier, it is not able to change polarity. To overcome this difficulty, an approximately constant pre-excitation is applied in the booster exciter by means of a separate winding (see Fig. 3), so that the boost excitation becomes symmetrical about the zero position, as indicated in Fig. 4a. This curve is identical with the transductor characteristic, but its position is shifted by the pre-excitation.

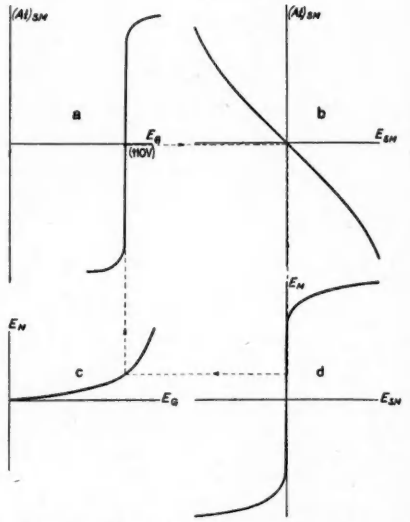
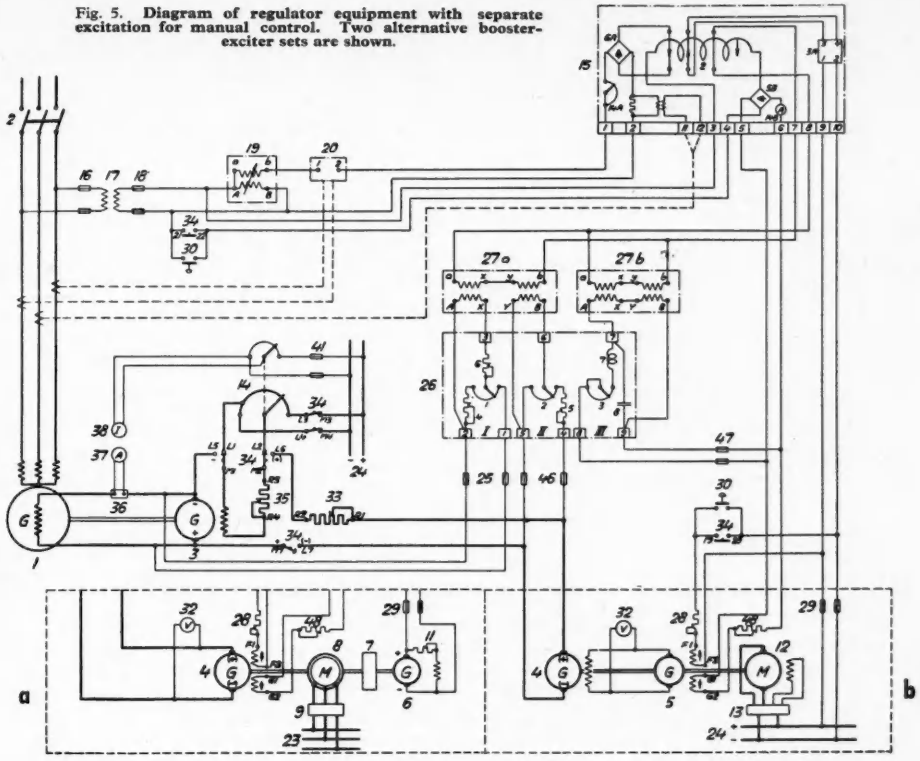


Fig. 4. **The excitation $(At)_{SM}$ fed to the booster exciter by the transductor** (Fig. 4a) **generates a booster exciter voltage** E_{SM} (Fig. 4b) **which determines the exciter voltage** E_M (Fig. 4d) **so as to produce the desired change in the generator voltage** E_G (Fig. 4c).

The true static relations in the closed control loop of Fig. 1 are illustrated in Fig. 4. As the self-excited exciter is an unstable element in the control loop, the control becomes astatic, i.e., the voltage is maintained constant irrespective of the other factors, such as the load on the generator. If it were required to have a voltage control dependent on the generator load, this could be achieved by supplementing the regulator with a compounding impedance. This introduces between the generator and the regulator a supplementary positive or negative voltage proportional to an adjustable combination of the active and reactive components of the generator current. The generator voltage is thus determined by the sum of the constant voltage on the regulator and the auxiliary voltage, and can be made to vary with the load in a predetermined manner. Adjustment of the controlled voltage, which is equivalent to a horizontal displacement of the transductor characteristic, is obtained by varying the ratio between the controlled voltage and the current flowing through winding

Fig. 5. **Diagram of regulator equipment with separate excitation for manual control. Two alternative booster-exciter sets are shown.**



(3) Exciter
(4) Booster-exciter.
(5) Auxiliary booster-exciter.
(6) Auxiliary a.c. generator.
(14) Field rheostat for the exciter.
(15) Transductor regulator.
(19) Voltage setting device.
(20) Compounding impedance.
(26) Rheostats for adjusting the recalling signals.
(27) Impulse transformers.
(34) Switch for selecting automatic and manual control.
(38) Position indicator for field rheostat (14).

a in Fig. 3. In the figure this is denoted by a variable-ratio transformer.

In order to obtain dynamic properties providing the necessary stability without any need for reducing the control speed, the control loop elements have been selected so as to have suitable time constants and amplification factors. In addition, by-pass recalling signals have been introduced in the regulator loop, each recalling element being an impulse transformer connected to the appropriate voltages in the regulator loop on the primary side, and to the transductor regulator input on the secondary side. Changes in the primary voltage induce currents in the secondary circuits which deliver transient control signals to the regulator in a direction tending to stabilise the regulator action.

REGULATOR EQUIPMENT

The regulator equipment may vary somewhat, especially as regards the method of hand control and the construction of the booster exciter set. Fig. 5 shows a diagram of control equipment in which the exciter field current is drawn from a separate source when manual control is used, and with two alternative booster exciter arrangements (Figs. 5a and 5b) for a.c. and d.c. This form of manual control is frequently necessary because of the ample voltage of the exciter, the excitation curve being so straight within the normal operating range that a manually-operated field rheostat is not practicable. Where a.c. is used for driving the single-stage booster exciter set (Fig. 5a), the d.c. voltage (24) required for manual control is usually supplied by a pilot exciter. In case (5b) the booster exciter is designed as a two-stage set, for a required output exceeding 2 kW. Accurate and continuous adjustment of the generator voltage is obtained by means of an induction regulator (19). The compounding impedance can also be inserted in this voltage-sensitive circuit, to transpose the measuring point to any point in the network at which it is desirable to maintain constant voltage. It can also be designed so that the regulator, although connected only to two phases, will exercise its control according to the magnitude of the positive phase-sequence component. A built-in stabilising circuit (terminals 11-12), which may be connected to a current transformer, is built in the regulator, in order to facilitate direct parallel operation. This circuit makes the voltage regulator sensitive to the reactive load so that the voltage drops about 3 per cent for an increase in the reactive output current corresponding to the rated current.

The stabilising device *S* of Fig. 3 is represented by (26) and (27) in Fig. 5. The part denoted by (26) is the setting device for recalling signals from the exciter voltage, the booster exciter voltage, and the control voltage delivered by the regulator. After passing through the two impulse transformers, these recalling impulses are added and the resultant control impulse enters the regulator through terminals (7) and (8).

Change-over from manual to automatic regulation and vice-versa is obtained without any disturbance in the network. Change-over to automatic control is accomplished by balancing the regulator while keeping

push-button (30) depressed so that the voltmeter for the booster exciter indicates zero, after which the change-over switch (34) may be turned to automatic control without causing any change in the field current to the exciter. The reverse operation is performed by setting the field rheostat (14) to a value corresponding to the existing field current indicated by the instrument (38). This instrument is calibrated in the same manner as ammeter (37), both instruments giving identical readings when manual control is in operation. By adjusting the field rheostat until both instrument readings coincide, it is thus possible to change over from automatic to manual control without causing any fluctuations in the network. This setting may be made fully automatic by means of a relay combination, where a motor-operated field rheostat is used.

U. S. A.

Potentials set up by Thermal Gradients in Iron Immersed in NaCl Solutions

By H. H. Uhlig and O. F. Noss, Jr. (From *Corrosion*, Vol. 6, No. 5, May, 1950, pp. 140-143, 4 illustrations.)

The relative damage caused by galvanically coupling a piece of iron at high temperature to another piece at low temperature in an electrolyte is a question of practical importance. Combinations of this kind occur in designs of industrial equipment such as condenser tubes, water-cooled radiators, boiler tubes, stills, pasteurising equipment, etc.

The work reported herein is not a complete analysis of differential temperature effects concerning iron immersed in aerated NaCl solutions, but rather a contribution to the point of view that the potentials and consequent corrosion are not necessarily small, and appear to deserve further consideration.

EXPERIMENTAL SET-UP

Potentials were measured in sodium chloride solutions and, in a few instances, in ferrous sulphate. To minimise gradual change in concentration or temperature of the electrolyte, the cell was set up in a ten-gallon earthenware crock. The solution was kept at a constant temperature of 25° C by means of several feet of Tygon tubing through which cold water circulated, thereby withdrawing heat supplied continuously by the hot electrode. A motor stirrer, and a glass tube through which air entered the electrolyte for aeration completed the auxiliary equipment. The electrodes consisted of two U-shaped seamless steel tubes immersed about 6 inches. Steam could be passed through either electrode by means of suitable connections. This permitted balancing out any slight differences in potential of one electrode compared with the other owing to factors other than temperature difference. The efflux steam temperature was followed by means of a thermometer inserted in a suitable metal well, and the steam supply adjusted so that the temperature remained at 100° C.

The electrodes were first pickled by inhibited acids, washed, then immersed in the electrolyte, and both short-circuited until their potentials approached each other to within at least a centivolt.

To avoid thermoelectric effects at the wire connections, a 6-inch piece of tubing of the same stock as the electrodes was split longitudinally, and two of these split sections were spot-welded to the electrodes. These split sections, in turn, were spot-welded to several inches of iron wire, the ends of which were soldered to copper wire. This precaution was necessary to avoid potentials at dissimilar metal junctions similar to those set up in thermocouples.

The electrodes were mounted in a manner allowing variable submersion and any desired distance of separation. Potentials were measured using a student-type potentiometer.

MEASUREMENTS IN SODIUM CHLORIDE SOLUTIONS

The first series of potential measurements was in aerated 3 per cent NaCl. With steam through one electrode and the other electrode at 25° C, the potential difference reached a steady state value in relatively short time and was reproducible to within about ± 4 mV. The steam connections were then interchanged and the potential measurement repeated.

In all cases, the hot electrode at 100° C was anode to the cold electrode at 25° C. The potential difference remained steady at 0·024 ± 0·004 V under the specific conditions of aeration and stirring already described. Variation of these conditions produced somewhat different values of the potential.

EFFECTS OF CONCENTRATION AND STIRRING

More dilute solutions of sodium chloride showed a decreasing potential difference between hot and cold electrodes, but with the hot electrode remaining the anode (Fig. 1). The value became 0·015 volt for aerated 0·125 per cent NaCl compared with 0·024 volt for 3 per cent NaCl.

The effect of stirring was observed by comparing potentials with the motor stirrer in operation and similar potentials with the motor stirrer shut off. The potentials decreased on absence of stirring as shown in Table I. The decrease was about the same for the various

Table I.

Effect of Stirring on E.M.F. of Cell $Fe_{100°}$ | Aerated NaCl Sol'n | $Fe_{25°}$ *

Concentration of NaCl :	E.M.F., Volt With Stirring	E.M.F., Volt Without Stirring	Difference
3·00 per cent	+ 0·024	+ 0·015	0·009
1·50 per cent	+ 0·022	+ 0·012	0·010
0·53 per cent	+ 0·019	+ 0·010	0·009
0·125 per cent	+ 0·015	— 0·002	0·017

*For positive e.m.f., hot electrode = anode.

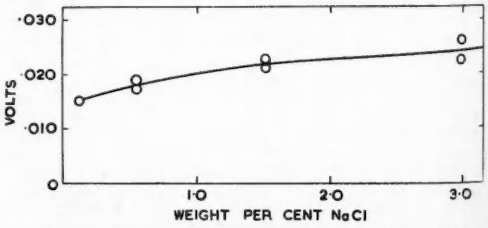


Fig. 1. **Effect of NaCl concentration on potential difference between 100° C steel electrode and 25° C steel electrode. (Hot electrode is anode).**

concentrations of sodium chloride except for the solution of highest dilution (0·125 per cent NaCl). At the latter concentration, the polarity of the cell reversed sign, the hot electrode becoming the cathode.

Because both electrodes initially were allowed to remain in the aerated solutions in order to establish steady state potentials, both the electrode surfaces were covered with corrosion products by the time potentials were recorded.

MEASUREMENT OF SHORT-CIRCUIT CURRENT

Using a " zero resistance " ammeter, the total current on short circuiting the cell in aerated stirred 3 per cent sodium chloride was 4 mA. Values for more dilute sodium chloride concentrations were somewhat less, and are recorded in Fig. 2. Since 12 in. of the ¼-in. diameter electrode were immersed, the corresponding current density in 3 per cent NaCl is 0·00043 ampere per sq. in. and the equivalent corrosion rate of the anode caused by this current is 0·03 ipy. This represents the initial corrosion rate caused by galvanic coupling of hot iron to cold iron, as in the cell described above, and is about three or more times the normal expected corrosion rate in aerated solutions of this kind. It is likely that the measured current diminishes over a period of days to a constant lower value, but this has not yet been checked experimentally.

Current through any cell is determined by the open-circuit potential, by the resistence of the electrolytic and metallic conductors, and by the polarisation of the electrodes. Examination of the data, as discussed below, reveals that currents plotted in Fig. 2 are evidence of polarisation control rather than resistance control. The actual operating cathode potential E_c can be expressed in terms of the open-circuit potential E_c' as follows:

$$E_c = E'_c - f_c I/A_c \quad .. \quad .. \quad (1)$$

where A_c is the area of the cathode, I is the total current, and f_c is the function expressing the relation between polarisation potential (back e.m.f.) and current. In some cases, the polarisation is approximately linear with current, whereupon f_c becomes a constant. Also since A_c is constant, the following may be assumed to hold as an approximation:

$$E_c = E_c' - kI \quad \text{where } k \text{ is a constant.} \quad (2)$$

Likewise at the anode:

$$E_a = E_a' + k' I \quad .. \quad .. \quad .. \quad (3)$$

Since the operating potential of the cell E is equal to $E_c - E_a$ and the measured open-circuit potential of the cell E' is equal to $E'_c - E_a'$ we have, combining eqs. (2) and (3):

$$E = E' - (k + k')\, I$$

If R is the electrolyte resistance, Ohm's law provides the following relation:

$$I = [E' - (k + k')I]/R \quad \text{or}$$
$$I = E'/[R + (k + k')] \quad .. \quad .. \quad (4)$$

Therefore, the ratio of E'/I, which is the ratio of open-circuit potential to total current I, provides values of $R + (k + k')$. These are tabulated in Table II.

The fact that $R + (k + k')$ is approximately constant, increasing only for the 0·125 per cent NaCl concentration despite a 19-fold decrease in specific conductivity over that of 3 per cent NaCl solution, is evidence that the polarisation factor $(k + k')$ is more important than ohmic resistance R. The same conclusion is reached from the experimental fact that varying distance of electrode separation during measurement of short-circuit current had no effect on the observed value of current.

TABLE II.

Values of $R + (k + k')$ in NaCl Solutions.

NaCl Conc.	E' $Fe_{100°} - Fe_{25°}$	Short-Circuit Current, I	$E'/I = R + (k+k')$
3·00 per cent	0·024 volt	0·0040 amp.	6·0
1·50 ..	0·022	0·0040	5·4
0·53 ..	0·019	0·0033	5·8
0·125 ..	0·015	0·0019	7·9

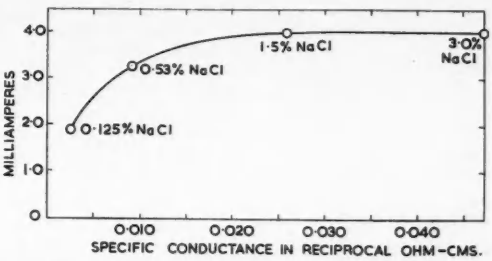


Fig. 2. **Effect of specific conductivity and NaCl concentration on short-circuit current for 100° C steel—25° C steel cell. (9·4 sq. in. of each electrode immersed, 2½ inches apart).**

MEASUREMENTS USING $FeSO_4$ AND DISCUSSION OF RESULTS

The foregoing results are obtained from potentials essentially irreversible and hence are not amenable to the theory for reversible differential temperature or thermo-galvanic potentials. In an attempt to measure reversible potentials, the electrolyte was changed to 0·1 molar $FeSO_4$. Data obtained in this electrolyte, however, changed rapidly with time and were extremely sensitive to rate of stirring. The polarity of the cell, and the actual value of the potential depended upon the relative amounts of Fe^{+++}, always present with Fe^{++}, since in the presence of air it was virtually impossible to avoid formation of trivalent iron. Addition of iron powder plus sulphuric acid to reduce the amount of Fe^{+++} shifted the potential from — 0·024 volt to + 0·055 volt but almost immediately the potential tended towards its former value, indicating rapid oxidation of ferrous ion. Qualitatively, whenever the ratio of ferrous to ferric ion was high, the hot electrode at 100° C was the anode, whereas when the ratio decreased, that is ferric ion concentration increased, the hot electrode became cathode. The polarity and magnitude of the potential in ferrous sulphate, therefore, depends on the relative oxidising or reducing capacity of the electrolyte as well as the temperature difference of the electrodes.

In aerated NaCl solutions, it appears plausible that the differential temperature currents are controlled largely by polarisation effects, and these are centred at the cathode. In other words, the increased corrosion of the hot electrode (the anode) caused by coupling with the cold electrode (the cathode) is controlled by the extent of oxygen depolarisation at the cathode. One interesting and important conclusion from these results, although not yet proved by actual corrosion weight loss, is that the hot electrode as anode in sodium chloride solutions and arranged as in the cell described above, will cathodically protect the cold electrode. The resulting cathodic current density of 0·43 mA per sq in. in 3 per cent NaCl is ample for cathodic protection of the cold electrode in the stirred solution.

In the absence of oxygen, differential temperature currents seem unimportant.

Potential measurements of the hot and cold electrodes in aerated 3 per cent NaCl versus O.1 N calomel cell, although not carried out in the same detail as in the previous measurements, demonstrated that the potential difference of hot and cold electrodes has its source

in the more ennobling effect of dissolved oxygen on the cold electrode than on the hot electrode. The initial potentials of hot or cold electrode in de-aerated 3 per cent NaCl were approximately the same at 0·83 V, but on admitting oxygen the cold electrode—calomel cell potential was 0·714 V compared with 0·748 V for the hot electrode—calomel cell. This agrees with the conclusion that the potential exists only when oxygen is present, is greater the higher the oxygen concentration, and is essentially an irreversible potential.

RUSSIA

The Drying of Electrical Machines by the One-Turn Method

By D. M. ANDRIANOV. (From *Electricheskie Stantsii*, Vol. 20, No. 10, October, 1949, pp. 37-38, 3 illustrations.)

IN the one-turn method of drying of electrical machines, the shaft of the machine is used as a primary winding for the induction of electromagnetic forces.

The method was first used for drying a rolling mill motor of 7,000 hp, 700 volts d.c., 40-100 rpm, of a total weight of 240 tons. Subsequently it was used for drying eight large a.c. and d.c. motors of a total capacity of 25,000 hp.

The shaft is connected to the mains through a single-phase transformer (in the case of the 7,000 hp motor mentioned above, two welding transformers, each designed for 380/50 volts and a secondary current of 397 amps., were used in parallel, see Fig. 1), the secondary terminals of which are connected to respective ends of the shaft by means of tightly fitting bushings. One end of the shaft must be insulated from the frame of the machine; in the case of machines with bearing blocks, this can be achieved by putting a sheet of insulating material underneath one block, and in the case of smaller machines, by inserting a layer of insulating material in the bearing.

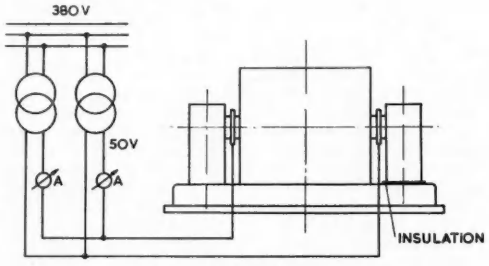


Fig. 1. **Circuit diagram.**

The intensity of the current flowing through the shaft must be set in such a manner that the temperature increase during the drying period does not exceed the limits allowed by the type of insulation used in the machine; more accurately, the highest temperature of the iron of the rotor or the stator must not exceed these limits. In the case of the 7,000 hp motor mentioned, the current ranged from 500 to 600 amps. The temperature of both the rotor iron and winding was measured in the uppermost, middle, and lowest parts of the machine. The temperature of the rotor winding in the highest part of the rotor was kept at 75° C. The temperature of the iron was about 5 to 10° C higher. In the middle part of the rotor, the temperature of the winding was 1 to 3° C, in the lowest part it was about 10 to 11° C below that of the highest part. This considerable temperature difference between the upper and lower parts of the rotor was due to the fact that the lowest part was already situated well below the floor level of the mill. After installing 5 electric radiators near this part of the machine, an almost uniform temperature was obtained throughout.

The drying took 10 days to complete and was carried out during the summer at an ambient temperature of 20 to 25° C. Fig. 2 shows the temperature and the insulation resistance of the winding, and Table I the resistance of the insulation of the different windings of the motor during and after drying. For drying of the other machines, the temperature of the iron was raised as high as 95 to 100° C, which allowed of reducing the required period to 5 to 6 days.

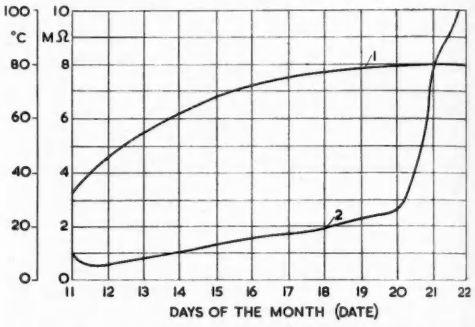


Fig. 2. **Temperature and insulation resistance of the rotor winding of a 7,000-hp motor during drying.**
(1) Winding temperature in the upper part of the rotor.
(2) Insulation resistance.

TABLE I.

Winding	Resistance, megohms			
	At beginning of drying (22° C)	Lowest	At end of drying (hot)	Lowest resistance after one hour
Rotor	0·5	0·4	12	16
Shunt winding ..	1·2	0·2	30	70
Compound winding	0·1	0·07	1	48
Auxiliary poles ..	1·5	0·2	5	70

In the case of sets consisting of more than one machine, the current is fed at the ends of the common shaft, so that the machines are dried together. The drying of the larger machines can be completed individually. Machines in which the rotor is provided with ventilating ducts or which have wheel-type rotors can be dried by inserting a copper conductor of adequate size through the rotor and connecting this to the transformer, instead of using the shaft for this purpose. This conductor must, of course, be insulated from the stator.

At present, special drying transformers are being manufactured which are designed for a low voltage output of up to 1,000 amps. at 24 to 28 volts. These are equipped with automatic circuit breakers which are actuated when the temperature of the machine reaches the required value, by thermocouples inserted in the air gaps of the machine being dried.

XUM

New Fully-Automatic Voltage-Regulating Equipment

By M. WIEDERKEHR. (From *Schweizerische Technische Zeitschrift*, No. 7, February 16, 1950, pp. 89-92, 4 illustrations.)

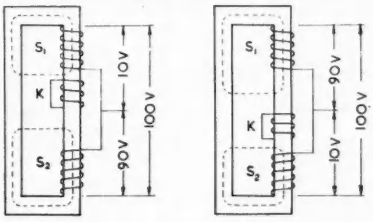
Variable voltage transformers occupy a predominant position among the various types of static regulators used, owing to their high efficiency, moderate cost and high reliability. This article describes transformer regulators in general and gives details of a novel voltage regulating equipment consisting of a series transformer and a slider transformer.

VOLTAGE regulation with variable voltage transformers is generally obtained by automatic variation of the transformer ratio according to the fluctuations of the supply voltage from its nominal value. For very large outputs the transformers are provided with coil tappings, selected by neutral switches and connected to the load by power switches.

The tapped-coil transformer has reached a very advanced stage of development, and would also be generally adopted for medium and low power ratings if it were not for the fact that for small-size designs the cost of the auxiliary regulating components becomes disproportionately high.

Various other selecting systems have been developed. One of these, for instance, has a contact rotating on the coil periphery to select the windings. As it is mechanically convenient to have the contact arm supported by bearings along the axis of the coil, the iron core is designed with an air gap, and this leads to a stronger magnetising current, higher magnetic forces at the core poles, stronger transformer hum, and reduced short-circuit strength.

Another design with an E-shaped core and very long legs has similar disadvantages. The core has two air gaps at one end, so that one of the coils can be shifted out of the main flux linkage to obtain the required voltage regulation. The sliding-type transformer with windings embedded in slots in the laminations also belongs to this class and has similar limitations.



Figs. 1a and 1b.

A particularly interesting type of variable ratio transformer is shown in Figs. 1a and 1b. It has no tappings and no interrupting or sliding contacts and is, therefore, short-circuit proof to a considerable extent. The transformer is a closed-core design with two fixed coils on one of the transformer legs. These coils are series-connected and arranged so that their magnetic fluxes are in opposition, and constitute the primary and secondary windings of an auto-transformer. The flux generated by each of these coils extends over the entire central core portion between the two coils, and is closed over the air gap between the two legs of the core. The central core portion is of considerable length in order to have a low magnetic resistance. It carries a movable short-circuit coil *K* which can be shifted in either direction along the leg, and with this arrangement the two coil voltages can be varied by altering the impedances without varying the overall voltage.

This transformer has, however, a high no-load current. A modified design is therefore required, which, however, should retain the essential features of the system, i.e., it should avoid the use of tappings with step switches and have no interruptions of the flux in the iron mass. An improved circuit can be obtained by using, for instance, two transformers, each with a primary and secondary winding. The primaries are connected in series, and the secondaries are also in series but with magnetic fluxes in opposition. By providing for a magnetic induction above the saturation point in one transformer, and below the saturation point in the other, the system can be designed to give a constant secondary voltage. Owing to its high reactive current consumption, this type of voltage regulator unfortunately has a relatively low efficiency and a distorted voltage curve. Its advantages are, therefore, appreciable mainly in the low power range, up to a maximum of a few kilovolt-amperes.

A good regulator should consist of simple and well-proven components to be economical and reliable in operation. This has been one of the basic design considerations applied in the development of a standard series of fully-automatic 380-volt three-phase voltage regulators. These regulators reduce a $\pm$ 10 per cent fluctuation in the mains voltage to a $\pm$ 1 per cent fluctuation. Fig. 2 shows a circuit diagram for a regulator of this type. The regulator equipment comprises two transformers, viz., the series transformer *ST* and the slider transformer *RT*. The series transformer is a sturdy design with two windings per phase, part of its secondary being connected in series with the network for a voltage not exceeding one half of the voltage-regulating range, that is, 22 volts in the case considered. The primary winding is generally designed for 110 volts, in order to reduce to a minimum the power absorbed by the slider-type auto-transformer which

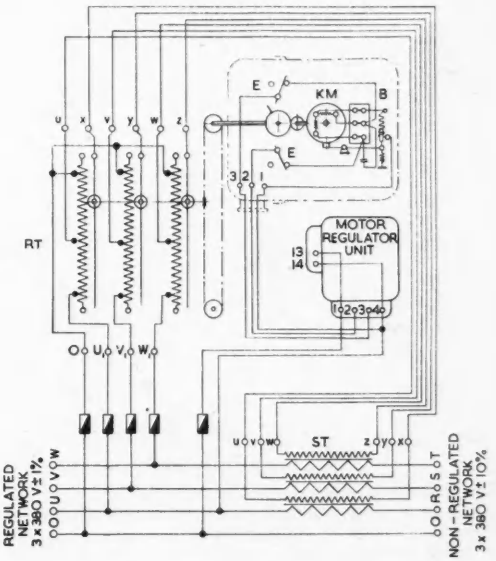


Fig. 2

feeds it. This slider transformer receives the direct network voltage, i.e., 220 volts phase voltage, on the primary side. From the centre of the coil and by means of a sliding contact on the secondary side, a positive or negative voltage varying between zero and ± 110 volts is supplied to the primary side of the series transformer.

The slider-type auto-transformer consists of a single-layer winding of insulated wire which is left bare over a certain section of the periphery and along the full length of the winding, in order to enable current to be taken from any of the winding wires from one end to the other of the coil. A disc-type carbon contact is used, carbon having a sufficiently high electrical resistance to maintain fairly low contact temperatures with the short-circuit currents generated by simultaneous contact of two adjacent turns, for the winding voltage considered, which is between 0·5 and 1·0 volt. The rolling contact used reduces wear and mechanical friction, and with the low winding voltages mentioned there is no risk of burning of the contact surfaces. Furthermore, no tappings or soldered connections are used, and this results in lower cost and increased reliability.

Ample protection against short-circuits is provided by the series transformer, which reduces the short-circuit current arising on the load side to one-fifth of its original value, and thus prevents any damage to the more sensitive regulating elements and the slider transformer. A further advantage obtained with the series transformer is that the slider transformer, the driving motor, and the relays, can be cut out of the circuit without it being necessary to disconnect the load circuit from the supply voltage. This simplifies considerably any overhaul or maintenance work required, and the load circuit can operate without interruption. During the overhaul the secondary windings of the series transformer are short-circuited at the terminals, in order to avoid the dangerous voltages which can occur in a current transformer with an open circuit.

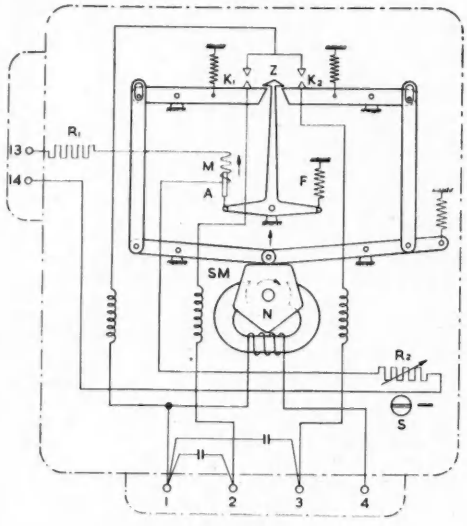


Fig. 3.

The voltage regulating circuit shown in Fig. 3 includes a differential relay for controlling the driving motor of the slider transformer.

The measuring apparatus shown in Fig. 3 is connected to a voltage coil M and to resistances R_1 and R_2. The electromagnetic force acting on the voltage coil is counterbalanced in a weighing arrangement by the tension of a coil spring F adjusted to the nominal value. A wedge-type contact breaker Z moves with the horizontal arm of the balance, which carries a relay magnet A at one end and the tensioning spring F at the other. The spring tension is adjusted so that equilibrium is obtained for the mean value of the voltage being regulated. When the primary voltage varies from this mean value, the magnet moves upwards or downwards in the voltage coil and causes the contact breaker to deflect towards the left or the right. On either side of the contact breaker are the contact pairs K_1 and K_2, which control the forward and reverse motions of the motor drive for the slider transformer. By means of an impulse transmitter system consisting of a small synchronous motor SM which operates a system of levers through a cam N, these contact pairs are continuously opened and closed as long as the contact breaker Z does not prevent their closing. When the system is in equilibrium, both contacts are blocked in the open position by the contact breaker Z. The impulse transmitter is designed and adjusted so that normal contact lasting about 1·3 seconds can take place approximately every 2·6 seconds.

The contact breaker arrangement and the impulse transmitter give considerable sensitivity and make it possible to operate powerful contacts with a minimum magnet force. The system also ensures smooth and gradual regulation and is neither affected by momentary flicker of the supply voltage nor has it a tendency to hunt.

The resistors R_1 and R_2 are made of constantan and their resistance is several times greater than that of the voltage coil. They are used for temperature compensation in order to make the relay response independent of temperature changes. The resistor R_2 is provided with an adjusting screw S for zero adjustment. A number of chokes and condensers have been incorporated in the circuit for screening purposes.

The slider transformer is driven by a single-phase squirrel-cage condenser motor KM (see Fig. 2) with a reactive power input of only 30 VA. In series connection with this motor is a braking coil B which brakes the motor as soon as the motor current falls off, in order to avoid over-regulation or exceeding the limits of the travel.

A sturdily designed gear unit with spur gearwheels is used to reduce the speed of travel, and a friction clutch affords protection against mechanical overloading under emergency conditions. In case of current failure in the auxiliary circuit, a hand crank is provided for rapid manual operation of the slider, using only a part of the reduction gear. Two automatic limit switches E built into the motor unit protect the slider transformer and its rolling contact head against overtravel beyond the end positions.

RADIOISOTOPES

(*Concluded from page* 199).

that British industry should be cautious and, therefore somewhat dilatory in making use of such revolutionary methods of research, probably because of the great health hazards to which personnel handling radioactive materials are exposed, unless strict precautionary measures are taken. That this reluctance was only temporary was borne out by the large attendance of research engineers, metallurgists and chemists at the recent week-end Conference at the University of Birmingham. At this Conference, lectures were given by members of the Physics Department of the University and by scientists on the staff of the Atomic Energy Research Establishment at Harwell, to introduce radioactive isotopes and associated techniques to potential users. It is felt that the Conference has made a great contribution towards promoting the use of isotopes in industry.

XUM

Change Wheel Gearing

By O. Lichtwitz, M.I.Mech.E.

(Concluded from May issue).

Example 27. To cut a single start worm, $m = 5{\cdot}5$. The corresponding linear pitch is $(\pi/25{\cdot}4) \times 5{\cdot}5$ inches.

The value (1) for $\pi/25{\cdot}4$ leads to the gear train .. .. $\dfrac{11 \times 47}{4 \times 95} = \dfrac{110 \times 94}{80 \times 95}$

The value (2) for $\pi/25{\cdot}4$ leads to the gear train .. .. $\dfrac{20 \times 10}{7 \times 21} = \dfrac{100 \times 50}{35 \times 105}$

The value (6) for $\pi/25{\cdot}4$ leads to the gear train .. .. $\dfrac{127 \times 3}{70 \times 4} = \dfrac{127 \times 90}{70 \times 120}$

The value (7) for $\pi/25{\cdot}4$ leads to the gear train .. .. $\dfrac{12 \times 11}{97} = \dfrac{120 \times 110}{97 \times 100}$

The value (8) for $\pi/25{\cdot}4$ leads to the gear train .. .. $\dfrac{17 \times 2}{5 \times 5} = \dfrac{120 \times 85}{75 \times 100}$

The value (9) for $\pi/25{\cdot}4$ leads to the gear train .. .. $\dfrac{110 \times 11}{7 \times 127} = \dfrac{110 \times 55}{35 \times 127}$

The gear train based on the value (2) involves an error of only 1 in 123,686. The length of a worm does not exceed a few inches; but even in a thread 10 feet long the accumulated error would be only 0·001 inch.

Table V (see May issue) renders computing of gear trains unnecessary even in many cases of leads not within the range of the table.

Example 28. To cut worms, d.p. 10, with 1, 2, 3, 4, or 5 starts, in a lathe with $\frac{1}{4}$ in. lead screw; gears 97 and 127 are available.

1 start: Table V indicates the gear train $(97 \times 40)/(65 \times 95)$.

2 starts: $2 \times \dfrac{97 \times 40}{65 \times 95} = \dfrac{97 \times 80}{65 \times 95}$. The same result is to be found in Table V for d.p. 5. Indexing is simplified by $(80 \times 97)/(65 \times 95)$, that is, by placing the gear 80 on the spindle stud.

3 starts: $3 \times \dfrac{97 \times 40}{65 \times 95} = \dfrac{120 \times 97}{65 \times 95}$. Indexing can easily be performed by means of the gear 120 on the spindle stud.

4 starts: The lead is the same as the pitch for d.p. $2\frac{1}{2}$, but neither of the gear trains for that pitch in Table V permits indexing of the number 4.

5 starts: Table V indicates, for d.p. 2, the gear train $(105 \times 95)/(25 \times 127)$. Indexing is carried out by means of the gear 105 on the spindle stud.

If, as in Example 28, a four-start worm is required, it is necessary to compute a gear train near to

$$\frac{\text{pitch of lead screw}}{\text{lead to be cut}} = \frac{0{\cdot}5}{1{\cdot}2566} = \frac{1}{2{\cdot}5132} = \frac{10000}{25132} =$$

2500/6283; generally, however, it is improbable that a gear train consisting of standard gears will be found which complies with both conditions, i.e., that the value is sufficiently near to the required ratio and that it permits indexing of a required number.

Worms based on the circular and diametral pitch are extensively used in Great Britain, and it is easily possible to meet the task of renewing a metric worm of foreign origin. The system recommended by the British Standards Institution is, however, different from all these systems, as it is based on the inch-module. The module is the reciprocal value of the diametral pitch, and gear trains for cutting such worms are found similarly as for diametral pitch worms.

Example 29. To cut one-start worms in a lathe with $\frac{1}{4}$ in. lead screw, British Standards Institution practice, module:

(a) 0·125 in.; (b) 0·13 in.; (c) 0·175 in.; (d) 0·19 in. Gears available from 20 to 120 in steps of 5, as well as the gears 97 and 127.

(a) As 0·125 is the reciprocal value of 8, the pitch is identical with d.p. 8, for which Table V contains three gear trains.

(b) The linear pitch for $m = 0{\cdot}13$ in. is $0{\cdot}13\pi$ inch. The ratio of the change gears is $0{\cdot}13\pi/0{\cdot}25 = (13/25)\pi$.
The value (5) for π leads to a suitable gear train

$$\frac{13}{25} \times \frac{5 \times 49}{6 \times 13} = \frac{49}{30} = \frac{70 \times 35}{20 \times 75}.$$

(c) The linear pitch is 0·175 π inch, and the required ratio is $(0{\cdot}175/0{\cdot}25)\ \pi = 0{\cdot}7\ \pi$. The value (8) for π leads to the gear train $(7/10) \times (22/7) = 22/10 = 110/50$.

(d) The linear pitch is 0·19 π inch, and the required ratio is $(0{\cdot}19/0{\cdot}25)\ \pi = (19/25)\ \pi$. The value (3) for π leads to the gear train

$$\frac{19}{25} \times \frac{8 \times 97}{13 \times 19} = \frac{97 \times 8}{25 \times 13} = \frac{97 \times 80}{50 \times 65}.$$

If none of the values for π is suitable, a gear train is best evaluated in the way which will be demonstrated in Examples 30 to 32 for abnormal pitches.

Threads with abnormal pitches are sometimes required in cutting taps or thread gauges which are subsequently hardened, or in cutting the moulds for threads in thermosetting plastics. In order to counteract shrinkage, the pitch must be cut correspondingly larger.

If an abnormal pitch is required, it is advisable first to look into Tables III to V which may contain a suitable value.

Example 30. To cut a tap for 14 t.p.i. in a lathe with $\frac{1}{4}$ in. lead screw; gears from 20 to 120, increasing by 5, are available; the steel is known to require an allowance of 0·18 per cent for shrinkage.

The pitch must be 0·18 per cent larger, or the number of threads per inch must be approximately 0·18 per cent, i.e., about 0·025, smaller than 14. The required ratio is $4/(14 - 0{\cdot}025) = 4/13{\cdot}975 = 160/559$. By means of continued fractions, the following scheme is obtained.

		3	2	39	2
1	0	1	2	79	160
0	1	3	7	276	559
			2	1	0
+	—	+	—	+	

The available gears are equivalent to gears with all numbers from 4 to 24, and only numbers up to $23 \times 24 = 552$ need be considered.

By using the convergents 2/7 and 79/276 for combining, the best approximation is found in

$$\frac{(-8\times 2)+(1\times 79)}{(-8\times 7)+(1\times 276)} = \frac{63}{220} = \frac{21\times 3}{22\times 10} = \frac{105\times 30}{100\times 110}$$

The thread actually cut has $(220/63)\times 4 = 880/63 = 13{\cdot}968$ t.p.i.

Computing of gear trains is very simple if, as in Example 29, only change gears in regular intervals of 5 (or 4, or 6, etc.) teeth are considered. If, however, in the case of Example 29, a gear 97 is also available, the highest number is $24\times 97 = 2328$, involving incomparably more work; if a gear 127 should be available, Table I would not be suitable at all. In such cases it is simpler to try to find suitable gear trains as demonstrated in the following example; the calculations are best made by means of a slide rule, and only when suitable combinations of numbers seem to be obtained are exact calculations to be made.

Example 31. In the case of Example 30, additional gears 97 and 127 are available.

Gear trains near to 160/559 may be of one of the following forms:

(1) $\frac{a\times b}{97\times 127} = \frac{160}{559}$; $ab = 97\times 127\times \frac{160}{559} \triangleq 3{,}530$.

It is unnecessary to carry out the calculation more thoroughly; neither 3,530 nor any other near number can be divided into the product of two normal gears (Table I is best used for that purpose)

(2) $\frac{97\times 127}{a\times b} = \frac{160}{559}$; $ab = 97\times 127\times \frac{559}{160} \triangleq 43000$

As the highest possible product of two normal gears is $115\times 120 = 13{,}800$, no gear trains of that form are possible.

(3) $\frac{97}{127}\times\frac{a}{b} = \frac{160}{559}$; $\frac{a}{b} = \frac{127}{97}\times\frac{160}{559} \triangleq 0{\cdot}375$; $a/b = 3/8$ seems to be a suitable value. The number of t.p.i. is, in this case, $(127/97)\times(8/3)\times 4 = 13{\cdot}966$, so that the error is higher than in the result of Example 30.

(4) $\frac{127}{97}\times\frac{a}{b} = \frac{160}{559}$; $\frac{a}{b} = \frac{97}{127}\times\frac{160}{559} \triangleq 0{\cdot}219$. It is unnecessary to determine the latter number exactly; it is sufficient to see whether the slide rule shows two suitable numbers (multiples of 5) which have the same quotient. In the present case, there are no such numbers.

(5) $\frac{ab}{97c} = \frac{160}{559}$; $\frac{ab}{c} = 97\times\frac{160}{559} \triangleq 27{\cdot}8$.

Here again it is unnecessary to determine that number exactly. Without changing the setting of the slide rule, that number is multiplied by 20, 25, etc. Only such products are suitable which are multiples of 25, and a suitable one would appear to be $27{\cdot}8\times 90 \triangleq 2500$. In this case, $(ab)/c = 2500/90 = (100\times 25)/90$, and the gear train is $(100\times 25)/(90\times 97)$. The result would be $\frac{90\times 97}{100\times 25}\times 4 = 13{,}968$ t.p.i., or about the same result as was obtained in Example 30.

(6) $\frac{97c}{ab} = \frac{160}{559}$; $\frac{ab}{c} = 97\times\frac{559}{160} \triangleq 339$. We proceed as under (5), but without suitable result.

(7) $\frac{ab}{127c} = \frac{160}{559}$; $\frac{ab}{c} = 127\times\frac{160}{559} \triangleq 36{\cdot}3$. We proceed as under (5), and $36{\cdot}3\times 110 \triangleq 4000$ seems to be suitable. In this case, $ab/c = 4000/110 = (100\times 40)/110$, and the gear train is $(100\times 40)/(110\times 127)$, which leads to 13·970 t.p.i.

(8) $\frac{127c}{ab} = \frac{160}{559}$; $\frac{ab}{c} = 127\times\frac{559}{160} \triangleq 444$; this does not lead, however, to any suitable gear train.

The best result was thus obtained under (7).

If still better results are required, special gears must be provided.

Example 32. In the case of Example 30, the highest accuracy is required.

As a rule, a suitable approximation must be found as demonstrated in Chapter III. In the present case, however, numerator and denominator of 160/559 can be divided into suitable factors. As $160/559 = (8\times 20)/(13\times 43)$, special gears with 43 or 86 teeth make possible the gear trains $(40\times 20)/(43\times 65)$ or $(80\times 20)/(65\times 86)$.

As Examples 30 to 32 show, gear trains can be found as accurately as required. It is, therefore, unnecessary to resort to means such as setting over the tailstock. Disregarding the problematical accuracy of the pitch, this method cannot produce any but "drunken" threads, as the tool advances along the work with a uniform linear velocity, whilst the work does not rotate with a uniform angular velocity. The tailstock should, moreover, be brought out of alignment only where absolutely necessary.

(b) GEARING OF THE MILLING MACHINE

The milling machine in conjunction with an indexing or spiral head enables cutting of threads. Although the principle of connecting the rotary and the longitudinal movement is the same for lathe and milling machine, there is, nevertheless, an important difference. The lead screw of the lathe is driven by the spindle, the feed screw of the milling machine drives the spindle of the indexing head. It is difficult to cut threads with long leads in the lathe, whilst on the milling machine short leads give trouble. The machines are complementary to each other in this respect.

The feed screws of practically all makes of milling machines have $\frac{1}{4}$ in. pitch. Most indexing heads nowadays have a reduction gear with the ratio 40 to 1. If, in milling helices, gears of the ratio 1 to 1 are used between the feed screw and the indexing head, 40 revolutions of the feed screw are necessary for 1 complete revolution of the spindle. If the ratio of the change gears $\frac{\text{driving gears}}{\text{driven gears}}$ is r, the feed screw makes $40/r$ revolutions during 1 complete revolution of the spindle, which correspond to a longitudinal movement of the table of $\frac{1}{4}\times(40/r) = 10/r$ inches. The relation between the lead l in inches and the ratio r is, therefore, $l = 10/r$, $r = 10/l$.

Indexing heads are equipped with an almost uniform set of change gears with the following numbers of teeth:

24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100.

Example 33. To mill a thread with a lead of 16 inches. The ratio $r = 10/l = 10/16$, and it can be carried out by the gear train $(40\times 24)/(24\times 64)$.

Gear trains generally cannot be evaluated as readily as in Example 33, but there are complete tables in many books, and abridged tables are supplied by manufacturers. If, in a particular case, a very exact lead is required, and the tables do not contain a sufficiently

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close value, a gear train must be computed on the basis of the previous chapters.

The change gears of the indexing head are also used for differential indexing, cam milling and other operations. A detailed treatment would exceed the scope of this treatise.*

(c) GEARING OF THE HOBBING MACHINE

Change gears are extensively used on gear-cutting machines, and the hobbing machine is one of the most interesting in this respect. There are three groups of change gears for speed, feed, and indexing, and in the case of a machine with differential, a fourth group for the lead.

Speed and feed depend on the material to be machined, on the sturdiness of the machine, on the tool, and on the required quality (roughing or finishing). Small departures from recommended values are permissible, and the gear trains can readily be tabulated, except for the feed in non-differentially hobbing helical gears.

With the same exception as just mentioned, indexing does not involve serious problems. The gear trains must be exact; they are usually tabulated in handbooks for operators, and can in the case of an unusual number of teeth readily be computed by a simple formula.

In hobbing helical gears on a machine with differential, the gear trains for indexing and for feed are determined as for spur gears; the change gears for the lead must be evaluated very close to the amount which is given by a simple formula.

In hobbing helical gears non-differentially, the lead depends both on the index gears and on the feed gears. The lay-out and the principle of the hobbing machine without differential may be assumed to be known, and the following notations will be used:

N = number of teeth of the gear.
T = number of threads of the hob.
K = index gear constant.
M = feed gear constant.
R = index gear ratio.
F = feed gear ratio.
$f = MF$ = feed per revolution of the gear in inches.
L = lead of the gear in inches.

The relation between L, R, and F is

$$L = \frac{MN\,FR}{NR - KT}$$

Both an error in F, and an error in R, influence L, and small departures in these ratios can lead to a considerable error in the final result. Engineers less versed in mathematics may take it as a general rule that an error in R influences the lead in a much higher degree than an error in F.

Readers familiar with differentiation will find that the total differential of

$$L = \frac{MN\,FR}{NR - KT} \text{ is}$$

$$dL = \frac{MNR}{NR - KT}\,dF - \frac{KTMNF}{(NR - KT)^2}\,dR$$

By dividing the differential dL by the function L, we obtain

$$\frac{dL}{L} = \frac{dF}{F} - \frac{KT}{NR - KT}\,\frac{dR}{R}$$

If the infinitely small differentials dL, dF, and dR are replaced by the small but measurable quantities ΔL, ΔF, and ΔR, there is still the same relation, at least approximately,

$$\frac{\Delta L}{L} = \frac{\Delta F}{F} - \frac{KT}{NR - KT}\,\frac{\Delta R}{R}$$

$\frac{\Delta F}{F}$, $\frac{\Delta R}{R}$, and $\frac{\Delta L}{L}$ indicate the relative error in F, R, and L. The value $\frac{KT}{NR - KT}$ is always much greater than 1 (an impracticably coarse feed of $f = L/2$ would be necessary for rendering it to 1). In a later Example, that value will be 1500, so that $\frac{\Delta L}{L} = \frac{\Delta F}{F} - 1500\,\frac{\Delta R}{R}$. This indicates that an error in F of, e.g., 0·01 per cent will affect L with an error of about 0·01 per cent; but an error of 0·01 per cent in R will cause, disregarding the minus sign, a 1500-fold error in L, that is, an error of about 15 per cent.

As R has such a big influence on L, it is best to choose R as the basis for evaluating F. It is, of course, not possible to choose R arbitrarily, as F must have a predetermined value, at least approximately. It is, therefore, necessary to start from the required value f, and to compute

$$R = \frac{L}{L \pm f}\,\frac{KT}{N}$$

The minus sign is used if gear and hob are of the same hand (the recommended case), the plus sign if they are of opposite hand.

The next step is finding a ratio R which is very near to the evaluated R; the ratio R found is then the basis for the subsequent calculations, and F is found by

$$F = \frac{L\,(NR - KT)}{MNR};$$ if gear and hob are of opposite hand $(NR - KT)$ is replaced by $(KT - NR)$. The evaluated F is then replaced very closely by an available gear train.

Example 34. To hob a helical gear non-differentially $N = 40$, $L = 45{\cdot}333$ in., $K = 30$, $M = 0{\cdot}075$, f about 0·030 in., gear and hob of the same hand, $T = 1$, many gears available between 20 and 100 teeth.

$$\text{The ratio } R = \frac{L}{L - f}\,\frac{KT}{N} = \frac{45{\cdot}333}{45{\cdot}333 - 0{\cdot}030}\,\frac{30 \times 1}{40}$$

$= 0{\cdot}750497$. It would not be difficult to compute a gear train very near to that ratio; the ratio 0·7505 is, however, quite satisfactory, and it requires only the simple transformation $0{\cdot}7505 = 7505/10000 = 1501/2000 = (79 \times 19)/(20 \times 100) = (79 \times 38)/(50 \times 80)$. It may seem exaggerated to speak of an error at all in replacing 0·750497 by 0·7505, as it amounts to about 1 in 250,000. The influence of the error in R on F is, however, the same as on L, that is

$$\frac{KT}{NR - KT} = \frac{30 \times 1}{(40 \times 0{\cdot}7505) - (30 \times 1)} = \frac{30}{0{\cdot}02} =$$

$= 1500$ times the relative error in R. But even 1500/250000, or a departure of 1 in 167 from the intended amount of feed, is passable. The feed actually required is $f = \frac{L\,(NR - KT)}{NR} = \frac{45{\cdot}333 \times 0{\cdot}02}{30{\cdot}02} = 0{\cdot}0302019$, that is 1/149 more than the originally intended value. (The difference between 1/167 and 1/149 is due to the fact that the former amount is based on the assumption of an infinitely small error in F.). The feed gear ratio is $F = \frac{f}{M} = \frac{1}{0{\cdot}075} \times 0{\cdot}0302019 = 0{\cdot}402692$.

*Readers are referred to the author's book, "Indexing and Spiral Milling," published by Messrs. George Newnes, Ltd.

It may be assumed that the lead must be exact to three decimals of 1 inch, or that the error shall not exceed $\pm$ 0·0005 in.; this corresponds to a relative error of 0·0005/45·333, or about 1 in 100,000. The relative error of F should also, therefore, not exceed 1/100000, or the limits of F should be 0·402692 $\pm$ 0·000004. Some gear trains with the ratio between 0·403688 and 0·402696 are

$$\frac{79 \times 22}{52 \times 83} = \frac{869}{2158} = 0{\cdot}402688, \text{ or } \frac{79 \times 33}{78 \times 83}$$

$$\frac{41 \times 38}{53 \times 73} = \frac{1558}{3869} = 0{\cdot}402688$$

$$\frac{37 \times 34}{44 \times 71} = \frac{629}{1562} = 0{\cdot}402689, \text{ or } \frac{74 \times 34}{71 \times 88},$$

$$\text{or } \frac{68 \times 37}{71 \times 88}, \text{ or } \frac{51 \times 37}{66 \times 71}$$

$$\frac{39 \times 33}{47 \times 68} = \frac{1287}{3196} = 0{\cdot}402691, \text{ or } \frac{78 \times 33}{68 \times 94}, \text{ or } \frac{66 \times 39}{68 \times 94}$$

$$\frac{55 \times 31}{58 \times 73} = \frac{1705}{4234} = 0{\cdot}402692$$

$$\frac{47 \times 21}{43 \times 57} = \frac{329}{817} = 0{\cdot}402693, \text{ or } \frac{47 \times 28}{43 \times 76},$$

$$\text{or } \frac{47 \times 35}{43 \times 95}, \text{ or } \frac{94 \times 21}{57 \times 86}, \text{ etc.}$$

$$\frac{26 \times 23}{33 \times 45} = \frac{598}{1485} = 0{\cdot}402694, \text{ or } \frac{52 \times 23}{33 \times 90},$$

$$\text{or } \frac{52 \times 23}{45 \times 66}, \text{ or } \frac{46 \times 26}{33 \times 90}, \text{ etc.}$$

and several other gear trains.

As the width of the gear considered in Example 34 would be but a fraction of the lead, there would practically be no traceable lead error. The accuracy aimed at would not be necessary in practice, and the assumption was made in order to demonstrate how easily gear trains can be found even under difficult conditions.

It is often stated that it is difficult to produce on a hobbing machine without differential, sufficiently exact right and left-hand helices with the same helix angle, by means of a common tool. The following example may show that this argument is not very well founded.

Example 35. To hob on the machine considered in Example 34, by means of the same hob, the mating gear with the same number of teeth, the same lead, opposite hand of the helix.

$$\text{The ratio } R = \frac{L}{L+f}\,\frac{KT}{N} = \frac{45{\cdot}333 \times 30}{45{\cdot}363 \times 40} =$$

0·749504, which may be replaced by $\frac{38 \times 20}{26 \times 39} = \frac{380}{507}$

= 0·745507.

$$\text{The feed is then } f = \frac{L\,(KT - NR)}{NR} =$$

$$\frac{45{\cdot}333\,[30 - 40\,(380/507)]}{40\ (380/507)} = \frac{45{\cdot}333\,(10/507)}{40\,(380/507)} =$$

$$45{\cdot}333/1520 = 0{\cdot}029824.$$

In order to find the feed gear ratio, the feed is divided by 0·075, or multiplied by 40/3. $F = \frac{40}{3} \times \frac{45{\cdot}333}{1520} =$

15·111/38 = 0·397658. Similarly as in Example 34, a tolerance of $\pm$ 0·000004 may be assumed, so that F may be between 0·397654 and 0·397662. By means of continued fractions, without interpolation, the ratio 68/171 = (17 × 4)/(19 × 9) = 0·397661 can be found, and it can be carried out by the gear train (34 × 24)/(38 × 54), or (36 × 34)/(38 × 57), or (51 × 24)/(38 × 72), etc. There are, moreover, many other suitable gear trains.

In conclusion, the author wishes to thank Mr. H. BEDFORD, B.Sc., for his kind assistance and valuable suggestions.

ITALY

A Tensometer for Cables of Aerial Ropeways

By S. BELLONE. (From *L'Ingegnere*, Vol. 23, No. 12, Dec., 1949, pp. 1316-1318, 2 illustrations.)

The instrument described here has been designed for the assessment of cable tension during the tensioning operation of cables to be anchored at both ends.

THE carrying cables of aerial ropeways with a large carrying capacity or designed for passenger transport are always anchored at their upper end and held at their lower end by counterweights. This ensures to some extent that the maximum tensile load will be within certain limits. The tension of the cable without the moving load is then determined by means of the known relations

$$T_1 = C$$
$$T_2 = C + qh$$

where T_1 = tension at lower end of cable, T_2 = tension at upper end of cable, C = counterweight [kg], q = weight of cable per unit length [kg/m], and h = difference in level [m].

Ropeways of medium or low carrying capacity frequently have their carrying cables anchored at both ends. Such cableways are used for the transport of ores or timber, and for military purposes. The carrying cables are normally anchored at the upper end, in the power station, then relieved along their free span; they are finally loaded at the lower end by means of a winch or other suitable means, and then anchored. The winch is controlled so that it will not exceed the maximum permissible value for the design considered. In many cases, however, the personnel in charge of the erecting work are apt to assess the cable tension by eye, and although the men are generally experienced in work of this kind, errors in assessment have been known to occur which have led to unfavourable results, particularly in regard to the durability of the cables. Such errors are particularly apt to occur in the erection

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of transportable semi-continuous ropeways, which are frequently used in the exploitation of forest areas.

The apparatus of the optical clinometer type described below is designed to eliminate this drawback, and to provide the erectors of cableways having cables anchored at both ends, with a sufficiently simple means of assessing the tension of the cables during erection, so that they will be able to avoid exceeding the permissible limit. In addition, the tensometer can also be employed to take an approximate measurement of the tension of a steel cable already erected but not carrying any extra loads, and either anchored or held by counterweights; this equally applies whether the cable is used for carrying or pulling the load and whether it is designed for passenger or goods transport.

THEORETICAL PRINCIPLE

The apparatus is based on the principle that the equilibrium curve of an unloaded cable can be regarded as a parabola instead of a catenary, the parabola passing through the given end points and having the same parameter.

The equation of the catenary is

$$y = p \cosh (x/p) = p\left[1 + \frac{(x/p)^2}{2!} + \frac{(x/p)^4}{4!} + \frac{(x/p)^6}{6!} + \ldots\right]$$

The approximation consists in taking the first two terms only, so that

$$\cosh (x/p) = y/p \simeq 1 + \frac{x^2 p^2}{2!}$$

Hence $$x^2 = 2p(y - p)$$

is the equation of the parabola approximating the catenary.

Let l = horizontal projection of the span length [m]; h = difference in height of the two ends of the span [m]; c = chord of the span [m]; θ chord angle [deg]; α_1, α_2 = angles of the tangents of the parabola at its two ends [deg], q = weight of cable [kg/m]; p = parameter of parabola; H = horizontal component of cable tension T [kg]; f = maximum sag of the parabola at midway [m]; S = length of cable in the parabola [m] (see Fig. 1).

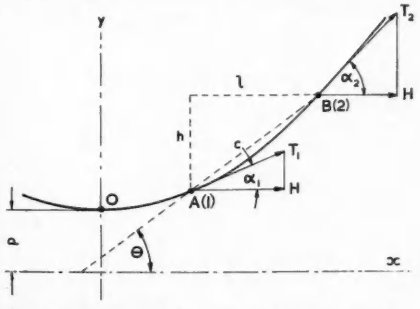


Fig. 1. **Parameters of the parabola approximating the catenary curve.**

Then $H = pq$; $T_1 = H/\cos \alpha_1$; $T_2 = H/\cos \alpha_2 = T_1 + hq$ [kg]. The parabolic curve is further characterised by the following relations:—

$$\tan \alpha_1 \simeq \frac{h}{l} - \frac{l}{2p} = \frac{h}{l} - \frac{lq}{2H} = \frac{h}{l} - \frac{c}{2p} = \frac{h}{l} - \frac{qc}{2H} \quad \ldots \quad \ldots \quad (1)$$

$$\tan \alpha_2 \simeq \frac{h}{l} + \frac{qc}{2H}$$

$$\left.\begin{aligned} \sin(\theta - \alpha_1) &\simeq ql/(2T_1) \\ \sin(\theta - \alpha_2) &\simeq ql/(2T_2) \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

$$\left.\begin{aligned} \sin \alpha_1 &\simeq \frac{h}{S} - \frac{q}{2T_1}(S - h^2/S) \\ \sin \alpha_2 &\simeq \frac{h}{S} + \frac{q}{2T_2}(S - h^2/S) \end{aligned}\right\} \quad \ldots \quad \ldots \quad (3)$$

$$f \simeq l^2/(8p) = ql^2/(8H) \simeq lc/(8p) = qlc/(8H)$$

$$\simeq \frac{T_1}{2q} + \frac{h}{4} - \sqrt{\left[\frac{T_1}{2q} + \frac{h}{4}\right]^2 - \frac{c^2}{8}} \quad (4)$$

$$S \simeq c\,[1 + 8f^2 l^2/(3c^4)] \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

The error which can be made by using these approximations is negligible in practice, as shown in an interesting example calculated by Zignoli.

Consider a length of metal cable used for aerial ropeways, not subjected to any external loads, and having the following specification: l = 1000 m; h = 500 m; q = 5 kg/m; p = 5000 m. We obtain directly: $H = pq$ = 25,000 kg; c = 1,118·03 m; θ = 26° 33′ 54″.

The exact calculation using tables of hyperbolic functions gives the following values: S = 1,119·524 m; f = 27·967 m; α_1 = 21° 17′ 29·6″; α_2 = 31° 32′ 04″.

The approximate values obtained with the aid of the above equations are: f = 27·950 m (error: 17 mm); α_1 = 21° 12′ 33″ (error: 4′ 56·6″); α_2 = 31° 27′ 27″ (error: 4′ 37″); S = 1119·522 m (error: 2 mm).

USE OF TENSOMETER

The tensometer employs the approximate algebraic formulae for the determination of the equilibrium curve of the cable regarded as a parabola.

To use the tensometer, it is assumed that l, h, q, and, therefore, $c^2 = l^2 + h^2$ and θ = arc tan (h/l) are known. By means of the apparatus, we can determine with close approximation the angles

$$\gamma_1 = \theta - \alpha_1 \text{ and } \gamma_2 = \alpha_2 - \theta.$$

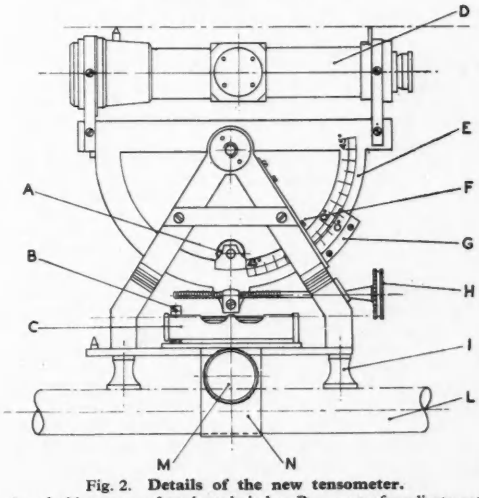


Fig. 2. **Details of the new tensometer.**
A = locking screw of graduated circle; B = screw for adjustment of the spirit level; C = level; D = telescope; E = graduated circle; F = vernier adjusting screw; G = vernier; H = micrometric screw for adjustment of the graduated circle; I = supports; L = steel cable, 8-16 mm diameter; M = lower clamping screw for fixing instrument on cable; N = fixing bracket.

(1) If we do not know the tensions T_1 and $T_2 = T_1 + hq$, we determine $H = T_1 \cos \alpha_1 = T_2$, and $p = H/q$; this gives S and f using eqs. (5);
(2) If we know the maximum sag f, we obtain H (eqs. (1) and (4)), $p = H/q$, $T_2 = T_1 + hq = H/\cos \alpha_2$, and S (eq. (5)) ;
(3) If we know the parameter p, we can determine $H = pq$, $T_1 = H/\cos \alpha_1$, $T_2 = H/\cos \alpha_2$, f and S.

In practice, the tensometer can be used to determine the horizontal tension H, by means of eq. (1), or the tensions at the ends, T_1 and T_2, by means of eqs. (2), for any length of cable already erected. For this purpose, the instrument is placed at the lower end A of the cable (see Fig. 2), a few centimetres above the anchoring system and the pulley, and by tightening the lower screw it is solidly clamped to the cable which can be regarded as practically coinciding with the geometric tangent at A. The apparatus is checked to make sure that it is in the vertical position. The telescope of the tensometer is then raised until it is pointing at the upper end B of the span. On the graduated circle a direct reading is taken of the angle $\gamma_1 = \theta - \alpha_1$, which is used in applying eqs. (1) and (2). It is also advisable to read off the angle $\gamma_2 = \alpha_2 - \theta$ at the upper end B, and to take as a final result the arithmetic mean of the two values.

The great practical advantage of this tensometer is, as previously stated, that it makes it possible to establish a fully reliable value during the tensioning operation for cables which are also anchored at the lower end. By using a winch or other suitable means, the cable is tensioned; the tensometer is then clamped at A in the vertical position, a few centimetres from the anchoring system and pulley, with the telescope locked at the angle $\gamma_1 = \theta - \alpha_1$, corresponding to the tension H, while T_1 and T_2 are obtained from the table of specified values.

During the tensioning operation, the instrument raises itself gradually with the cable until by looking through the telescope it is possible to see the upper end B of the span. At this point the required limiting value is reached, and the cable tensioning operation should then be stopped. A check made at B, by measuring the angle $\gamma_2 = \alpha_2 - \theta$, is always advisable.

NOTE.—If a higher degree of approximation is required in the calculation of the angles of the curve at the end points by using eqs. (1), one should add to both tan α_1 and tan α_2 the correction term $e^2q/(Hl)$, where e is the eccentricity of the maximum sag, obtained from a special table computed by Professor V. Zignoli: Mathematical study of equilibrium curves for cables of aerial ropeways. "Delle Funivie," Rome, ENIOS, 1934. Thus, in the example given, using the correction terms, the errors in the computation of the angles α_1 and α_2 are reduced to —1·6″ and —1″ respectively.

U. S. A.

Current Design Practices for Gas Turbine Power Elements

By H. D. EMMERT. (From *Transactions of the ASME*, Vol. 72, No. 2, February, 1950, pp. 189-200, 21 illustrations.)

The following article discusses certain principles of design and analysis for power elements of commercial gas-turbine plants. It is restricted to the consideration of a single component, i.e., the basic power element. The design of the turbine blade path from the standpoint of fluid mechanics is dealt with below, and the basic principles of stress analysis used for the blade carrying elements will be the subject of a second instalment to be published next month.

GENERAL DESIGN PRINCIPLES

Importance of Optimum Design. The net output of a gas-turbine plant is represented by a surplus in power produced by an expansion element over the power demand of a compression element. On an average, the ratio of gross power to net power is of the order of 2 or 3 to 1. Assuming a constant compressor demand, an increase of 1 per cent in turbine efficiency results in a gain of from 2 to 3 per cent in net output and efficiency. This indicates the importance of improving power-element performance to the maximum practical level.

Reliability and long life are of primary importance for commercial turbines. These requirements are reflected by a tendency towards conservatism in temperature and stresses in such machines when compared with aircraft-turbine practice. Since performance requirements for commercial applications do not permit any appreciable sacrifice in fuel economy, it is necessary to offset the effects of moderate cycle temperatures by increasing power-element efficiencies at some expense in over-all weight and size.

Basic Turbine-Design Principles. The most important factors which control the type of construction adopted for any specific gas turbine are as follows:

(*a*) Desired efficiency level.
(*b*) Expected useful service life.
(*c*) Required maximum-load capability.
(*d*) Desirable variable-load characteristics.

The particular problems associated with commercial applications indicate that certain design principles have definite advantages:

(1) The premium placed on performance almost invariably results in the employment of a multi-stage construction.
(2) Large volumetric flows inherent in high-capacity designs necessitate correspondingly large annular flow areas. These are best provided by high ratios of active blade height to blade-ring mean diameter. Three-dimensional flow considerations therefore become of considerable importance.
(3) High speeds are desirable to reduce physical size as much as possible.

BLADE-PATH DESIGN AND PERFORMANCE ANALYSIS

Turbine Efficiency. The internal efficiency of a turbine relates the actual power produced by the turbine stages to the theoretical power available in an isentropic expansion from the total pressure and temperature at the turbine inlet to the static pressure at the turbine exhaust. It is a function of the following basic variables:

$$\eta_i = (\eta_s)\,(RF) - \%\,\Delta h_L \quad .. \quad .. \quad (1)$$

where

η_i = internal efficiency, per cent
η_s = average stage efficiency, per cent
RF = reheat factor
$\%\,\Delta h_L$ = leaving loss, per cent

The stage efficiency takes into account the losses incurred in each element due to gas friction and leakage. It is primarily dependent upon the operating conditions and configuration of the staging, and it can be controlled within fairly wide limits by the designer.

The reheat factor originates from the fact that as the gas progresses through the blading, friction and leakage cause the actual temperatures to be slightly above those corresponding to an expansion without losses. This has an apparent effect of increasing the over-all efficiency slightly above the incremental stage efficiency.

Leaving loss is proportional to the residual kinetic energy contained in the gas leaving the turbine. The magnitude of the leaving loss is primarily dependent upon the relation between the total volumetric flow of gas and the annular flow area at the last row of blades. The large volumetric flow in high-capacity units necessitates the use of a considerable amount of exhaust annulus area if the leaving loss is to be held to an acceptable value.

Stage Performance. Both theory and experience indicate that the following basic factors almost completely control the performance of an individual stage:

(1) Primary factors: (*a*) Isentropic velocity ratio
(*b*) Stage reaction
(*c*) Leakage configuration

(2) Secondary factors: (*a*) Pressure ratio
(*b*) Parasitic losses
(*c*) Viscosity effects

Numerous tests have shown that isentropic velocity ratio is the most important criterion establishing general performance level of a stage, regardless of the actual physical configuration. This parameter is defined by the following relation:

$$\frac{u}{c_0} = \sqrt{\frac{\Delta h_u}{\Delta h_s}} \qquad (2)$$

where

u = blade velocity at blade-ring mean diameter, fps
c_0 = gas velocity corresponding to stage isentropic enthalpy drop, fps
Δh_u = stage equivalent blading energy, Btu per lb
$= \dfrac{u^2}{2g\mathcal{J}}$
Δh_s = stage isentropic enthalpy drop, Btu per lb
g = 32·17 ft/sec²
$\mathcal{J}$ = 778·26 ft-lb/Btu

The number of stages to be employed in a specific turbine design is determined from the selection of a desirable velocity ratio at the normal operating load. The curves in Fig. 1 show that high velocity ratios are required for good efficiency. However, the number of stages rises rapidly as the velocity ratio increases. A considerable amount of investigation of each design is necessary to obtain a satisfactory balance in this respect.

The second major factor affecting stage performance is the stage reaction. This parameter is best explained by reference to Fig. 2 which shows the energy quantities in a stage on an enthalpy-entropy diagram. The expansion through a stage is accomplished in two distinct steps, namely, a partial expansion through the fixed blade ring, followed by an additional expansion through the moving blades. The distribution of energy assigned to these two successive expansions is at the control of the designer and is established by means of the stage reaction. Stage reaction is defined as the ratio of the isentropic enthalpy drop across the moving blades to the isentropic enthalpy drop across the stage.

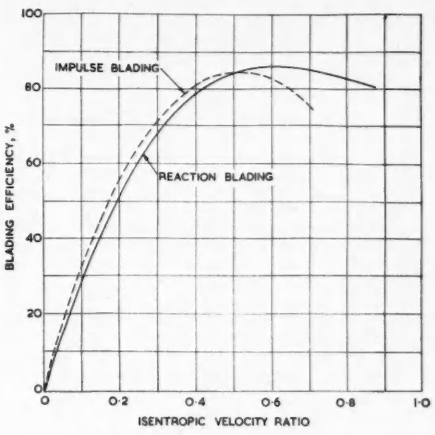
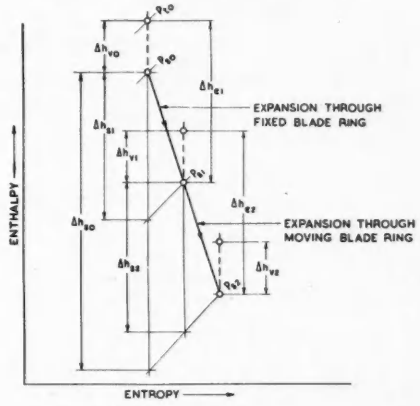


Fig. 1. Typical blading-efficiency curves.



Δh_{v0} = KINETIC ENERGY ENTERING STAGE
Δh_{s0} = STAGE ISENTROPIC ENTHALPY DROP
Δh_{s1} = ISENTROPIC ENTHALPY DROP ACROSS FIXED BLADE RING
Δh_{e1} = EFFECTIVE KINETIC ENERGY LEAVING FIXED BLADE RING
Δh_{v1} = KINETIC ENERGY ENTERING MOVING BLADE RING (RELATIVE TO MOVING BLADE RING)
Δh_{s2} = ISENTROPIC ENTHALPY DROP ACROSS MOVING BLADE RING
Δh_{e2} = EFFECTIVE KINETIC ENERGY LEAVING MOVING BLADE RING (RELATIVE TO MOVING BLADE RING)
Δh_{v2} = KINETIC ENERGY LEAVING STAGE

Fig. 2. Enthalpy-entropy diagram of stage expansion.

Two opposing considerations influence the amount of reaction used in a specific turbine. Purely from the performance standpoint, it is preferred to use a stage reaction of approximately one half. This corresponds to the conditions in normal reaction blading, and maximum efficiency is obtained provided velocity ratio is high and leakage losses are low. If the turbine isentropic enthalpy drop is large, the number of stages may become excessive. When this occurs it is frequently desirable to decrease the number of stages by decreasing the average velocity ratio of the high-pressure elements. The reaction in these elements is also lowered, and they assume the form of a normal impulse-blading configuration. This is particularly desirable when high temperatures and stresses are involved, since a reduction in stage reaction lowers the effective impact temperature on the moving blades.

Leakage control plays a dominant part in establishing

stage efficiency level. Gas leakage through operating clearances between rotating and stationary parts represents a loss of working fluid. It is therefore desirable that clearances be kept to the minimum value consistent with reliability, and that the leakage gas path be made as tortuous as possible.

Both shrouded and open-ended blades are used. For blades operating at high tip velocities, shroud weight adds considerably to the centrifugal stress at the blade base. If the blade is long, the leakage and end-loss effects can be kept small and at the same time safe operating clearances at the blade tip can be maintained. Open-ended construction is preferred in such a design. Leakage control for short blades is better if shrouding is installed.

Spindle glands are normally designed with step-type labyrinth seals. This same construction is used for interstage seals in disk-and-diaphragm blade paths.

Pressure ratio is listed as a secondary factor influencing stage performance. For single-stage turbines, pressure ratio may become of major importance. Compression shock losses and poor control of fluid direction may seriously depreciate efficiency when high pressure drops are employed across individual elements. However, the pressure ratio across each stage of a multistage turbine is generally small, with a corresponding decrease in influence on the individual elements.

Parasitic losses resulting from disk or spindle gas friction are not high in gas turbines of the type under consideration. However, they are accounted for in performance estimation through empirical formulae derived from test analysis.

The influence of viscous forces within turbine staging is sufficiently small in large units so as to be indeterminate in the presence of other more powerful factors.

Basic Stage Analysis. Requirements for optimum performance at high speed make it necessary in most cases to design the blading configuration for a new turbine to conform to a specific application. It is therefore essential that there be available detailed procedures for turbine-stage analysis. The designer is thereby able to predict the approximate actual conditions existing within each element and can proportion the blades accurately with respect to shape and setting.

Blading analyses by means of filament-flow theory and vector diagrams still represent the most powerful tools available to the practical gas-turbine designer. Two basic requirements must be met in applying vector diagrams to blading performance and flow analysis:

(1) The velocity magnitudes must represent integrated mean values rather than highly peaked or depressed local values.
(2) The velocity directions must represent mean fluid directions, and not necessarily blade-profile geometric angles.

It cannot be assumed that the actual flow conditions within a stage are in exact agreement with predictions from simplified vector-diagram analyses. However, reasonable correspondence between prediction and performance has been thoroughly demonstrated, provided suitable control is exerted by continual comparison with test results.

The basic variables in blade-ring calculations are shown in Fig. 3. The data apply to either fixed or moving blades, provided the velocity magnitudes and directions are taken relative to the blade-ring under consideration. The effective kinetic energy at the ring outlet is computed from the following relation

$$\Delta h_{r2} = \phi^2_E (\Delta h_{s2} + C_i \phi^2_v \Delta h_{r1}) \quad .. \quad (3)$$

where

ϕ^2_E = expansion-energy coefficient.
C_i = incidence coefficient.
ϕ^2_v = kinetic-energy coefficient.
See Fig. 3 for other symbols.

The primary loss resulting from turbulence and wall friction within the blade passage is reflected by the expansion-energy coefficient. This coefficient is determined from the profile width and deflection angle, as shown in Fig. 4. Tests indicate that the effective energy

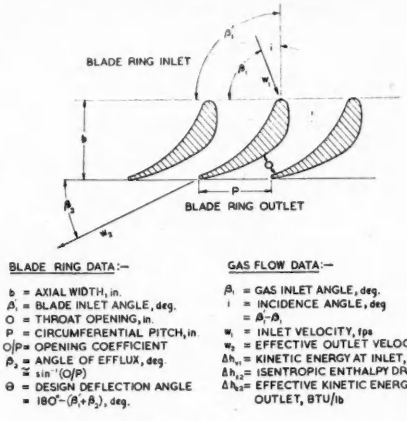

BLADE RING INLET
BLADE RING OUTLET
P
BLADE RING DATA:—
b = AXIAL WIDTH, in.
β_1 = BLADE INLET ANGLE, deg.
O = THROAT OPENING, in.
P = CIRCUMFERENTIAL PITCH, in.
O/P = OPENING COEFFICIENT
β_2 = ANGLE OF EFFLUX, deg. = $\sin^{-1}$(O/P)
Θ = DESIGN DEFLECTION ANGLE = $180°-(\beta_1+\beta_2)$, deg.
GAS FLOW DATA:—
β_1 = GAS INLET ANGLE, deg.
i = INCIDENCE ANGLE, deg = $\beta_1-\beta_1$
w_1 = INLET VELOCITY, fps
w_2 = EFFECTIVE OUTLET VELOCITY, fps
Δh_{r1} = KINETIC ENERGY AT INLET, BTU/lb
Δh_{s2} = ISENTROPIC ENTHALPY DROP, BTU/lb
Δh_{r2} = EFFECTIVE KINETIC ENERGY AT OUTLET, BTU/lb

Fig. 3. **Blade-ring analysis.**

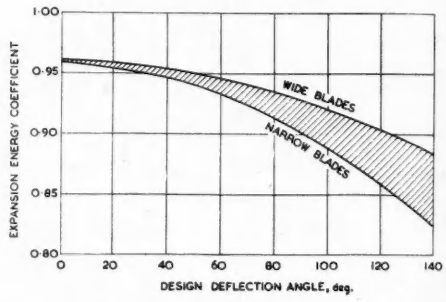


Fig. 4. **Variation of expansion-energy coefficient with design deflection angle.**

obtained from a given amount of inlet kinetic energy is less than that which is realized when the same quantity of available energy is supplied by pressure drop. In eq. (3) the inlet kinetic energy is reduced by a kinetic-energy coefficient. This coefficient is normally assumed to be equal to the expansion-energy coefficient. When the inlet velocity vector forms a definite incidence angle with reference to the blade leading edge, an additional

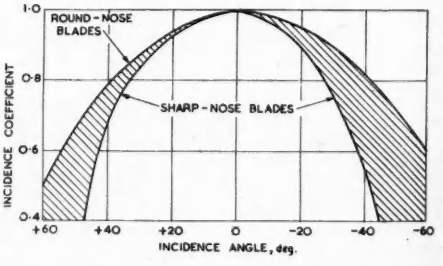


Fig. 5. **Variation of incidence coefficient with incidence angle.**

loss occurs which is evaluated by means of the incidence coefficient. This coefficient is a function of the blade-nose design and the angle of incidence as shown in Fig. 5.

The angle of efflux from the ring is assumed to be approximately equal to arcsine (O/P), where O is the blade throat opening and P is the blade circumferential pitch. The accuracy of this simple rule is adequate for small efflux angles.

Establishment of the average velocity magnitudes and directions within a stage permit the determination of tangential velocity components. Estimated blading output per pound of gas flow may then be found by entering these data into the basic turbine equation.

$$\Delta h'_w = \frac{u_1 c_{t1} - u_2 c_{t2}}{g\mathcal{J}} \quad .. \quad .. \quad (4)$$

where

$\Delta h'_w$ = blading output, Btu per lb.
u_1 = blade velocity adjacent to the fixed-ring outlet mean diameter, fps.
u_2 = blade velocity at the outlet mean diameter of the moving ring, fps.
c_{t1} = tangential component of effective velocity leaving fixed ring, fps.
c_{t2} = tangential component of velocity leaving stage, fps.

The gas flow is found from the continuity equation using the effective velocity, area, and gas density at the blade-ring throat. Net stage output may then be calculated by subtracting clearance and parasitic losses from the gross blading output.

Three-Dimensional Considerations. If the blades are installed with normal pitch at the blade-ring mean diameter, the pitch at the tip may become excessive and result in poor control of fluid direction. Furthermore, unless the flow is controlled properly, the tangential velocity components along the outlet plane of the fixed blade-ring tend to throw the fluid outward.

The three-dimensional flow problem has been attacked quite thoroughly using approaches based on aerodynamic theory. For practical purposes, however, a simple and adequate solution is obtainable from rather elementary conceptions. Consideration of the forces acting on an incremental mass of gas indicates that the static pressure at the fixed-ring outlet must gradually increase with radius in accordance with the following equation

$$\frac{dp}{dr} = \rho \frac{c_t^2}{r} \quad .. \quad .. \quad .. \quad (5)$$

where

p = static pressure at fixed-ring outlet, psfa.
r = radius, ft.
ρ = mass density of gas, lb-sec^2/ft^4.
c_t = tangential component of velocity leaving fixed ring, fps.

Three controlling premises are made in the practical design of blading where special provision is to be incorporated for maintenance of radial equilibrium:—

(1) The basic equation for radial stability of flow, as given in eq. (5) is to be satisfied over the entire outlet plane of the fixed blade ring.
(2) The mass flow through the stage is to be distributed evenly over the entire stage annulus.
(3) The isentropic enthalpy drop across the stage is to be constant at all radii in the stage annulus.

Stages designed in accordance with these conceptions exhibit the following characteristics:—

(1) The fixed blades have almost symmetric profiles at all radii.
(2) The moving-blade profiles vary with radius. At the inner radius, the profile shape approaches that of a normal impulse blade. An approximately normal reaction-blade profile is used at the mean radius. At the tip, the profile assumes the form of a low-cambered aerofoil of medium thickness.

Analyses of tests on both steam and gas turbines incorporating such blading have indicated that appreciable improvements in efficiency are attained in comparison with more conventional designs.

Turbine Performance. The performance of a complete turbine depends primarily upon the characteristics of the individual stages composing the turbine. However, it is essential that the design be established and controlled from the standpoint of the complete unit, rather than as an assembly of completely independent elements. Poor design of any one stage affects elements both upstream and downstream from that point.

Other factors than stage design may have appreciable effects on performance. Pressure drops in the inlet and exhause passages are particularly important. Low velocities, gentle changes in flow direction, and freedom from obstructions are essential if harmful reductions in both performance and load capability are to be prevented. Radiation losses may reach significant values in high-temperature units, particularly at light load, and adequate insulation is mandatory.

Overall turbine performance is determined analytically by combining the results of stage calculations and then correcting for external effects. For practical purposes the performance of a given turbine can be represented adequately in terms of the following simplified parameters

$$\left(\frac{W\sqrt{T_{t1}}}{p_{s2}}\right), \ (\eta_i) = f\left(\frac{p_{t1}}{p_{s2}}\right), \ \left(\frac{n}{\sqrt{T_{t1}}}\right) \quad (6)$$

where

W = gas flow, lb per hr.
T_{t1} = total temperature at inlet, deg. F abs.
p_{t1} = total pressure at inlet, psia.
p_{s2} = static pressure at exhaust, psia.
η_i = internal efficiency, per cent.
n = turbine speed, rpm.

Fig. 6 is a general performance map in terms of these parameters for a turbine rated at 12,000 gross bhp.

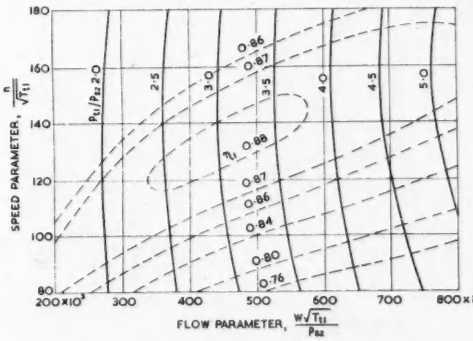


Fig. 6. Typical gas-turbine power-element performance map.

The calculation of such a chart represents the final step in the thermodynamic analysis of each turbine design. The accuracy of the overall design procedure is measured by the degree of correlation on such a chart between computed and test performance.

(*To be continued*).

DESIGN TRENDS AND T

OF MACHINE TOOLS

BY T

MILLING AND GRINDING MACHINES PART VII

A large-capacity universal thread grinder, Ex-Cell-O style 50, is illustrated in Fig. 163. It is adaptable to internal grinding of straight line and radius form threads. Work with externally threaded sections, too long for grinding at one setting, can be ground by *turning end for end* or inserting through the work spindle. The work spindle has an infinitely adjustable hydraulic drive. The leads obtained with the change

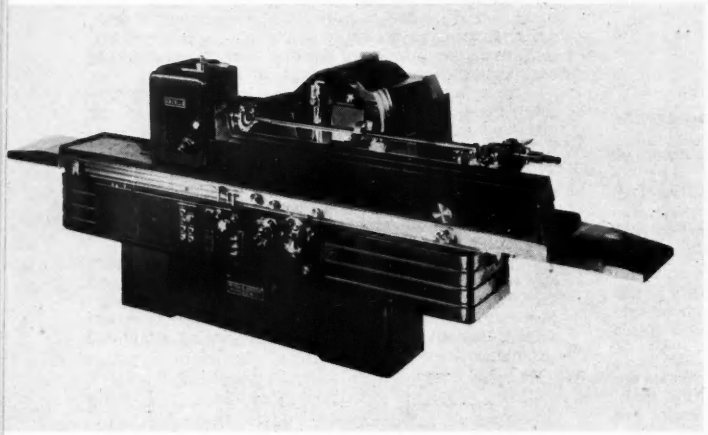


Fig. 163. **Ex-Cell-O Style 50 universal thread grinder.**
Max. diameter of work ground 8 in., max. swing 12 in., max. length between centres 68 in.

gears can be lengthened or shortened with the lead control. This makes it possible to grind odd leads and to hold accurate overall lead dimensions on exceptionally long work pieces.

Fig. 164. **Reishauer model NRK universal screw thread and worm grinding machine.**
Max. length ground 17¾ in., max. length between centres 27½ in., max. thread dia. 7·9 in.

The Reishauer universal thread and worm grinder, Fig. 164, operates by two basically different grinding methods, i.e., with the single-rib grinding wheel on the longitudinal bed principle, and with the multi-ribbed wheel on the infeed or plunge-cut principle. The latter principle is used with advantage when grinding from the solid blank. The machine is automatic and has a rapid return traverse. The pleasing lines of this machine are accentuated by the smooth unadorned surface of the base. This is in distinct contrast to the otherwise excellent design of the two preceding illustrations, where the horizontal lines are rather superfluous and do not easily lend themselves to cleaning.

The Holroyd thread grinding machine shown in Fig. 165 is seen grinding the profiles of an involute helicoid worm. It will grind worms of up to 12 in. diameter and is arranged for various forms of wheel trimming. The maximum length of wormshaft between centres is 36 in.

The Wickman optical profile grinder, Fig. 166, employs diamond or standard grit wheels to grind any desired profile in tungsten carbide or other hard metal direct from the drawing by using a 50 to 1 pantograph. This machine and the Taylor-Hobson "Genoptic" profile grinder, Fig. 167, which has already been described in this journal[28], can be classed among the best designed post-war British machine tools.

The "Matrix" No. 40 gear grinder, Fig. 168, employs the principle of gear tooth generation from the basic rack, which in this case is formed on the periphery of the grinding wheel in a continuous helix. This is similar to the hobbing principle, i.e., passing a rack tooth through the space of a revolving gear (Fig. 169). In addition to the revolving motion there is an axial motion of the gear which is generated from the blank. Spur as well as helical gears can be produced. The

THE STYLE

BY TIBOR HAAS, A.M.I.MECH.E., A.F.R.AE.S.

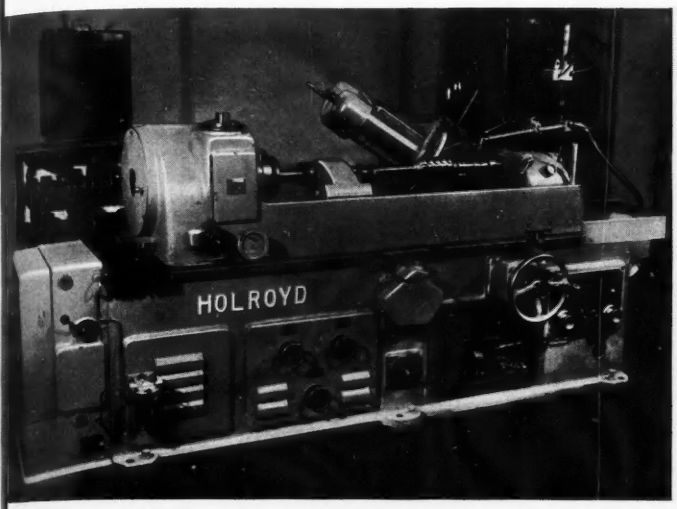


Fig. 165 (left). **Holroyd 12/36 thread grinding machine.**

accuracy of the gear teeth is dependent on the rack form of the grinding wheel, and the dressing of the latter is therefore of the greatest importance.

The British " Orcutt " helical gear grinding machine (manufactured by The Gear Grinding Co. Ltd., Birmingham), Fig. 170, operates on the " formed wheel grinding " principle. This refers only to the involute and not the helix; the latter must be generated on all types of grinders. In this extremely rigid machine weighing over 9 tons, gears of 12 in. dia. can be ground. The grinding wheel and truing device are set to correct helix angle and locked in this position. It is only necessary to move the wheelhead in a straight line to the grinding position.

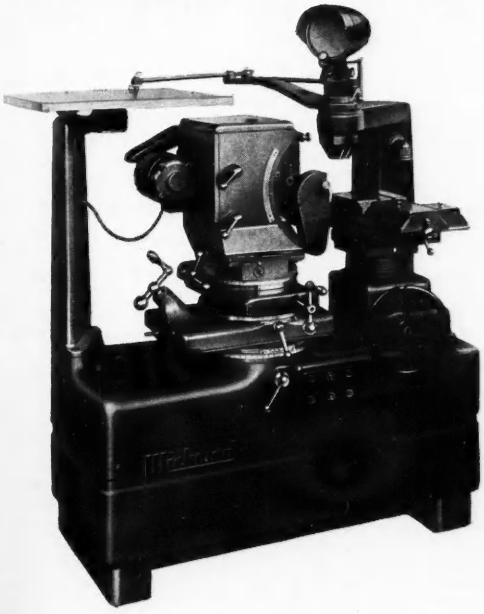
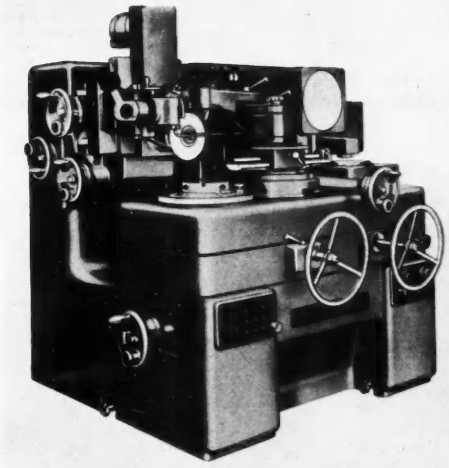


Fig. 166. **Wickman optical profile grinder.**
Capacity for work of 5⅞ in. length, 2½ in. depth and 2 in. thick.

Fig. 167 (below).
Taylor-Hobson " Genoptic " profile grinding machine



The Swiss Reishauer gear grinding machine, Fig. 171, employs the generating principle of grinding. The wheel is a single-thread grinding worm with rack profile and generates the theoretical shape of the tooth by means of an infinite number of enveloping curs. Spur gears and helical gears can be produced by this continuous automatic machine.

Some of the more recent tool grinders are shown in Figs. 172 to 174. The first two grinders are the Ex-Cell-O style 44 and style 49. The former is for precision finishing of all types of boring, facing and turning tools, the latter for conditioning of carbide, stellite and high-speed steel tools.

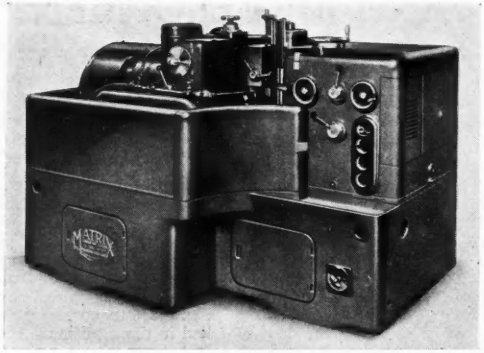


Fig. 168. **"Matrix" No. 40 gear grinder made by the Coventry Gauge and Tool Co., Ltd.**

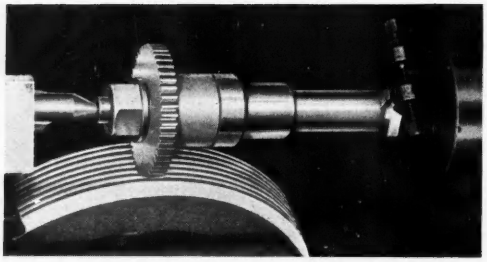


Fig. 169. **Generation grinding on the "Matrix" No. 40.** Work rotating continuously at a set rate while moving axially upward until completely formed, having passed above the centre line of the wheel. A reciprocating rolling movement of the work across the wheel uses the full wheel width.

The Wickman, a British tool grinder, Fig. 174, for servicing of all types of cutting tools, has a new form of table support and a very effective splash guard attachment. This grinder, when compared with the two former ones, should demonstrate convincingly that in machines at any rate, simplicity and beauty are almost synonymous.

Fig. 170. **The "Orcutt" helical gear grinding machine Modell H.K. III.** Front elevation showing wheel in truing position.

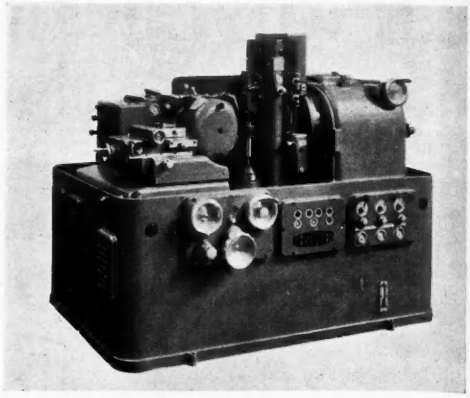


Fig. 171. **Reishauer ZA gear grinding machine.** Max. gear dia. 9½ in.

Fig. 172. **Ex-Cell-O tool grinder Style 44.**

Several types of completely special-purpose machines for specific parts, such as crankshafts, have been developed, where the operations are determined by the peculiarities of the part, but beyond showing one such machine, a crankshaft grinder, Fig. 175, no space can be devoted here to such machines. Special multi-wheel grinding machines using a number of wheelhead units can be built up for special purposes on the principle discussed under "Unit Construction" as applied to milling machines*. By using interchangeable wheelhead units, these can easily be regrouped or remounted on other "multiple-head" machines, resulting in economical employment.

*Milling and Grinding Machines, Part III of this series, *The Engineers' Digest*, Feb., 1950.

Fig. 173. **Ex-Cell-O tool grinder Style 49.**

Conclusions

We have come to the end of our survey of present-day machine tools, only a narrow section of which could be selected to illustrate trends and style. Of the accompanying 175 illustrations, perhaps 100 showed appearance design at its best. It is hoped that no really bad design was illustrated. However, without any intention whatsoever of offending the susceptibilities of particular firms, it can be said that many machines—and new ones at that—which violate the principles of good appearance design are on the market; harm may perhaps have been done by unqualified people who claim expert knowledge in this field. The fact remains that our civilisation, which is largely dependent on mass production, needs to exploit those inherent qualities of machines which would conform to the ideals of a higher cultural level made possible by machines of the modern age. A machine cannot be conceived in terms of primary qualities alone. The human factor should also receive due attention. Machine tools, taken as a particular instance, cannot be considered to be efficient on mechanical merits alone, unless they are easy to control and clean, and unless they are safe and conducive to the occupational and visual comfort of the operator. Here, beauty and efficiency have the same functions.

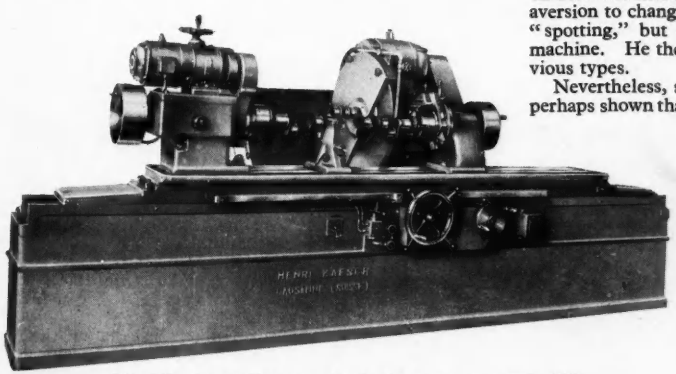


Fig. 175. **Henri Kaeser crankshaft grinder type LM 1500.**
1500 mm between centres.

When James Nasmyth, in 1831, set up a machine shop of his own, he fitted up a lathe which was to become—in his own words—"the parent of a vast progeny of descendants." Without wishing to carry this biological analogy too far, it is clear that if the machine tool is the only machine capable of reproducing itself, we must take care that her offspring do not become victims of passing fancy. Neither should we cling to out-of-date methods of production and finish. Colvin tells us in his book[29] that some machine builders still practice hand-scraping of the slides. Is there any doubt in their minds as to whether machine work is more accurate than handwork? In regard to appearance, the "spotting" complex dies hard. Slides and other surfaces are often—far too often—"spotted" with a scraper because it is assumed that this creates eye appeal to the customer. It is perhaps not so much a question of the engineer being indifferent to judgment on aesthetic merits as that of his fear of the customer's aversion to changes, not only in minor points, such as "spotting," but also in the whole conception of the machine. He therefore keeps up the tradition of previous types.

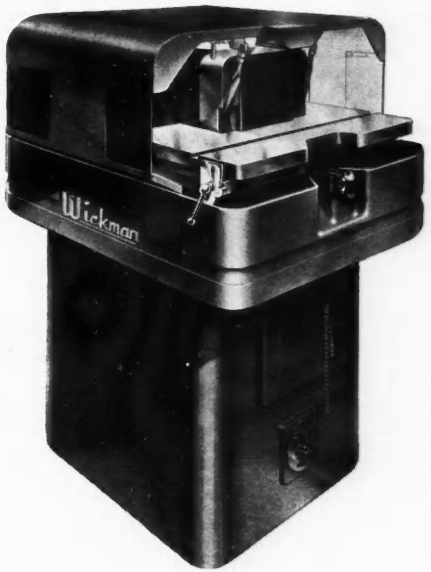


Fig. 174. **Wickman tool grinder.**

Nevertheless, some of the machines illustrated have perhaps shown that we are begining to break new ground.

If this paper has guided designers at least to some extent towards the road they ought to take, then it has served its purpose.

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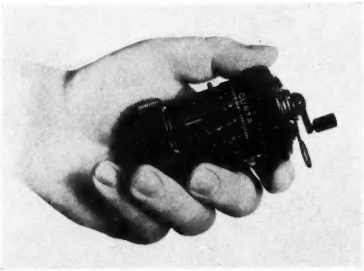
(29) "60 Years with Men and Machines," by Fred. H. Colvin, Publ. *Whittlesey House, McGraw Hill Co.*, New York and London, 1947.

New Materials, Processes and Equipment

POCKET SIZE UNIVERSAL CALCULATOR

Built like a chronometer, this all metal calculator weighs only 8 ozs and measures $3\frac{3}{8}$ in. in height by $2\frac{1}{16}$ in. in diameter. With 8 × 6 × 11 places (Model 1), the "Curta," like ordinary stationary hand operated calculators, will perform all four types of calculations and their derivations such as percentages, squares, cubes, extraction of square roots, etc. The tens are carried over till the last place in both dials; the easily learned, simple and noiseless operation of the calculator, ensures quick and reliable results.

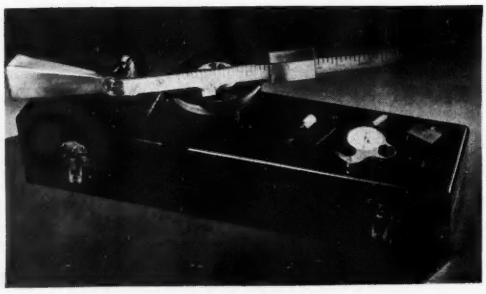


The setting unit with horizontal setting control above is placed on the cylindrical machine body, the counter and result dials being enclosed in a round carriage. The carriage can be displaced in 6 steps corresponding to the 6 places in the counter dial. The operating handle on the top of the machine will perform additions in its lower and subtractions in its upper position, always in a clockwise rotation. The counter dial can be reversed for division. A clearing device will clear either or both of the dials at random. Safety stops and locks prevent faulty operation and damage to the machine. The "Curta" is a product of Contina Ltd., makers of office and calculating machines, Mauren/Liechtenstein (Switzerland).

SHEAR HARDNESS AND DIAMOND SCRATCH TESTER

This instrument, manufactured by Taber Instrument Corporation, New York, is a precision tool for testing the quality of plastic materials and plastic coated surfaces to resist scratches, digs, scrapes and similar physical damage not classed as normal wear. It accurately measures the surface toughness and scratch resistance of a plastic or coated surface.

The tool selected is inserted in the scale beam which is then positioned on the mounting shaft so that the tool rests against a clear area of the specimen to be tested. The sliding weight is moved part way along the scale beam and a cut or scratch is made by turning the specimen by hand slowly and steadily in a counter-clockwise direction. The results are then calculated in accordance with instructions furnished with each instrument.



A.C. VOLT-AMMETER

This new model, A-5-1, manufactured by Pyramid Instrument Company, N.Y., is the third to be added to the series of small pocket size volt-ammeters. Like the first two, it has seven ranges: 6·5/13/26/65/130 amperes and 150/600 volts. The two original models, A-5 and A-6, are 6·5/13/26/65/130 amperes and 130/260 volts and 10/25/50/100/250 amperes and 150/600 volts respectively.

These volt-ammeters are designed specifically for maintenance men, engineers, electricians, and motor repair and service shops. The split-core transformer will handle conductors up to $1\frac{1}{8}$ in. in diameter. The transformer core is permanently insulated with a moulded plastic cover capable of withstanding 5,000 volts a.c.

The case and scale window are moulded in one piece of impact-proof plastic. The case is thoroughly insulated for complete protection. The scale is visible from any angle, and the range is clearly indicated. The movement is a large D'Arsonval jewelled movement with Alnico magnet, completely dust and moisture proofed. A plastic finger trigger opens the jaws, and the selector switch is operated with a flip of the finger. The meter has an accuracy of ± 3 per cent of full scale.

PLASTIC-METAL CASTING COMPOUND

A new casting compound that is neither a metal nor a plastic, yet partakes of the qualities of both, has just been developed by the Plastics Division of The Lockrey Company, College Point, N.Y. The new material, called Plasti-Metl, is the colour of copper, harder than some casting metals, yet can be poured into moulds at room temperature. With the aid of varying amounts of a catalyst, it can be made to set at room temperature without heat, or in an oven at low temperatures forming a hard, tough casting, metallic in appearance, which can be machined or polished with ordinary tools. It is a thermo-setting material which cannot be softened by heat once it is set, and is completely resistant to all common chemicals except strong alkalis. Plasti-Metl can be poured into rubber, elastomer, plaster, metal or clay moulds, with or without inserts, or slush-moulded. It can be used to cast forming moulds, short runs of moulded parts, machine-replacement parts, etc.

XUM

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

FUEL ENGINEERING

Ignition of Fuels by Rapid Compression

By C. F. TAYLOR, E. S. TAYLOR, J. C. LIVENGOOD, W. A. RUSSELL, and W. A. LEARY. (From *SAE Quarterly Transactions, U.S.A.*, Vol. 4, No. 2, April, 1950, pp. 232-274, 70 illustrations.)

THE auto-ignition characteristics of several fuels under various conditions of mixture strength, compression ratio, and temperature have been studied by means of a rapid-compression machine.

The behaviours of a knock inhibitor, tetraethyl lead, and a knock inducer, ethyl nitrite, have also been studied. Simultaneous records of pressure, volume, and the inflammation have been obtained.

These records show the diverse aspects of the auto-ignition phenomenon and indicate, among other things, according to the authors, that a comparison of the detonating tendencies of fuels must include not only a consideration of the length of the delay period but also an evaluation of the rate of pressure rise during auto-ignition.

Physical interpretations of the data are presented but chemical interpretations have been avoided. The work was exploratory in nature. The authors hope that the results will stimulate activity in this important branch of combustion research.

IRON AND STEEL

Magnetic Properties of Cast Steel

By V. ZEDNIK. (From *Schweizer Archiv, Switzerland*, Vol. 16, No. 3, March, 1950, pp. 65-75, 11 illustrations.)

THE use of cast steel in the design of electrical machinery affords considerable economic advantages and may also bring electrical advantages due to the coarser grain and greater isotropy of cast steel as compared with wrought steel. It is known that inhomogeneities of the crystalline structure, though they may increase the mechanical strength, lower the magnetic qualities of the material, but the influence of the individual alloying constituents as well as the history of the material on the magnetic properties has not yet been investigated in sufficient detail. Since normalised cast and wrought steels of similar composition possess roughly identical permeability values, it is permissible to infer that results obtained on wrought steels will also apply to cast steels. A large number of recent investigations on industrial as well as specially de-oxidised steels shows that there is no linear relationship between the magnetic permeability and the content of alloying constituents or impurities in the steel. The effect of various additions, is not simply additive. The complex existing relationship is especially pronounced for carbide-forming elements like chromium and manganese. Their percentage, compared with that of carbon, is of great influence. The heat treatment of the steel also plays some part, as it determines the distribution of the alloying elements in ferrite and cementite particles. The higher the alloying content in the ferritic regions, the greater is the disturbance of the lattice and the smaller the permeability. Small, uniformly distributed inclusions are comparatively less influential. For similar reasons, an effective de-oxidization is very important. It can be obtained by an excess of aluminium, which may reduce the ductility of the steel but does not adversely affect its permeability.

From the investigations described in the article, it is possible to draw conclusions regarding the separate influences of different alloying elements, additions, and impurities on the permeability. Segregations and the smaller density of the top half of a steel casting will usually result in reduced permeability of the material of that part, the extent of the reduction increasing with the size of the casting. However, by careful choice of the composition and complete de-oxidization, the magnetic properties of steel castings can be controlled within the required limits, even with materials of relatively high strength. It is finally noted that internal stresses produced in the test specimen by rough machining may lead to lower measured values of the permeability; it is safer to anneal such specimens. The methods of flux measurement also play a certain part. The usual Koepsel method gives lower results than the more accurate ballistic method, especially for steels with appreciable structural inhomogeneities.

METALLURGICAL ENGINEERING

On Fracture of Materials Taking Place in a Plane Parallel to the Direction of Thrust

By AKIMASA ONO. (From *Memoirs of the Faculty of Engineering, Kyushu University, Japan*, Vol. 11, No. 4, 1949, pp. 189-199, 4 illustrations.)

MATERIALS under pure uni-axial compression sometimes fracture, or rather split, in a plane parallel to the direction of the thrust. This seems to indicate the action of a tensile stress, which may be induced by compression if the homogeneous stress field is broken by the existence of a cavity. If, for example, a plate of infinite width with a central elliptical or circular hole is compressed by a force producing a uniform compressive stress p_0 at a great distance from the hole, a local tensile stress of equal magnitude p_0 will be induced at two opposite points of the circumference of the hole, the connecting line of these two points being parallel to the direction of thrust. In order to decide whether tensile cohesive fracture due to compression is possible under these conditions, a criterion is established by consideration of the variation of energies due to the growth of the dimensions of the hole. Neglecting the small amount of plastic deformation accompanying such a tensile rupture, it can be said that the work W done by the stress forces acting on the circumference of the hole is taken up by the elastic strain energy of the body, equal to $W/2$ and by the surface energy of the additional surface area created by elongation of the cavity. Assuming, in addition, certain geometrical conditions for the deformation of the cavity, e.g., that the width remains constant, we obtain an expression for the minimum compressive stress p_2 that may produce tensile cohesive failure. This may be compared with the critical uni-axial tensile stress p_1 which would induce cohesive failure in a similar material under tension*:

*A. A. Griffith, Proc. 1st Internat. Mech. Congress, Delft, 1924.

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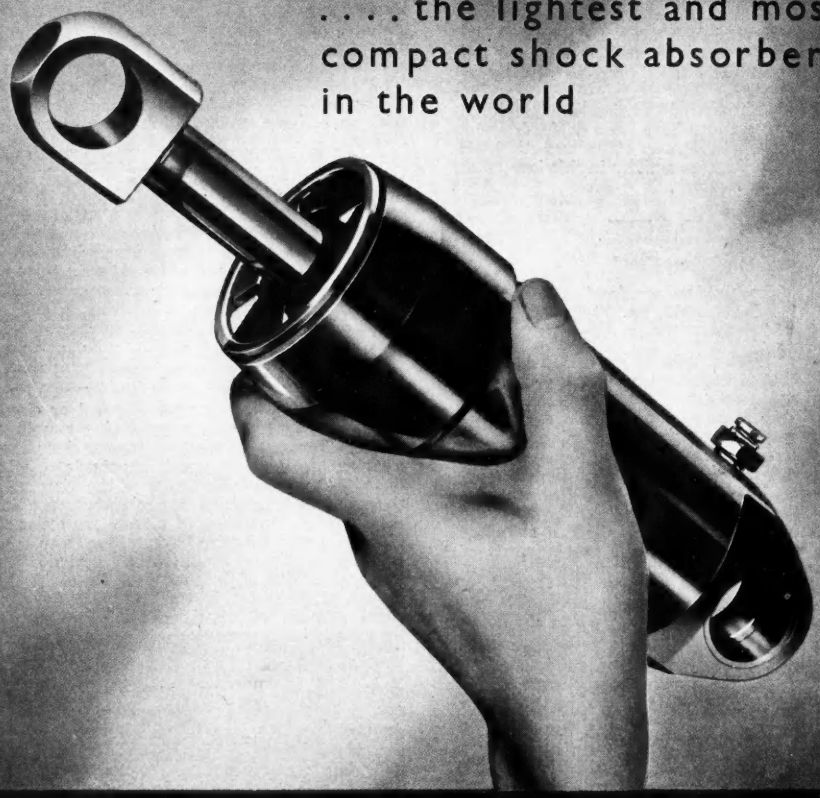

$$p_1 = \sqrt{\frac{2ET}{\pi c}}, \qquad p_2 = \sqrt{\frac{16ET}{\pi b(1-\sigma)}},$$

where E = Young's Modulus, T = surface energy of unit area of the material, c = major and b = minor axis of the elliptical cavity, σ = Poisson's ratio. For a given material, the ratio p_2/p_1 thus varies with $\sqrt{c/b}$.

The author has undertaken tests on various specimens of 6 × 6 × 4 cm size. Specimens made of agaragar† material always fractured in fission under loads of 2 to 3 lb. Specimens of wax or paraffin or a mixture of the two usually broke in the common shear fracture, but sometimes also showed the typical fission fracture parallel to the thrust of 500 lb or more. The fission started from the elliptical hole or, in one case, apparently from an existing hairline crack. Since the "radius of curvature" at the ends of a hairline crack may be of the order of a few Angström units, then assuming $c/b = 25$, about 10^{-4} to 10^{-5} in. would be found to be a sufficient length of crack to initiate fission fracture.

†Artificial culture-medium prepared from seaweed

METALS CORROSION

Electrolytic Descaling of Tanks

(From *Pacific Marine Review, U.S.A.*, Vol. 47, No. 4, April, 1950, pp. 36-37, 6 illustrations.)

ELECTROLYTIC descaling of rust, corrosion, and other scales has been progressively successful in recent years. Both in the United States and in this country, successful descaling of tanks and objects such as deck plating and corroded superheater headers has been reported.

Experimental electrolytic descaling of petrol and oil tanks aboard the tanker USS "Cimarron" consisted of supplying power from welding machines to an arrangement of anodes suspended in the tanks to be cleaned. In general, enough current was supplied to give a current density of 0·235 A per surface foot of tank area at a potential of 20-30V. The use of mild steel anodes and sea water as the electrolytic fluid assured economy of materials for the tests.

The vessel's cargo tank No. 2 required two operations, using two types of anodes and two power set-ups. Results were judged "fairly good" after two "shots." Operation 1 used twelve straight, flat bar anodes, arranged with four anodes getting power from each of three welding machines. It showed clean surfaces parallel to the anode axes and in the vicinity of the anode only.

Increasing the length and adding extra fins at the bottom of the anodes led to much better and more complete overall cleaning on Operation 2, which had three anodes powered by each of four machines. For Operation 3 (No. 8 wing tanks) six anodes in each wing tank were divided with three anodes being powered on each of four machines.

An important feature of the test was the proof that a soluble anode of mild steel, rather than an insoluble such as carbon, produces practically no hydrogen and no detectable chlorine.

A special problem of chemical deposits left on the tanks (flakes of calcium, magnesium, and sodium salts) would of necessity require special cleaning before use of tanks for carrying aviation or other light-weight petrol products. Wire brush cleaning or use of a stronger wash-down than sea water after cleaning were recommended for this problem. The experimenters also recommended further study to learn if a period of short reversal of current near the end of the process would assist in removing the deposits without affecting the magnetic state of the ship's hull.

It is concluded that "the electrolytic descaling method is practical and relatively economical" and should merit further study.

WELDING

Preliminary Results of Welding-Peening Investigation

By J. LYELL WILSON. (From *The Welding Journal, U.S.A.*, Research Supplement, Vol. 29, No. 3, March, 1950, pp. 97s-108s, 23 illustrations.)

SINCE the tendency towards cracking during the welding process, especially under conditions of high restraint, was attributed to the effects of shrinkage, loosely referred to as residual stress, and because the use of peening minimised such cracking, the practice of peening was assumed to be beneficial in reducing residual stresses.

The theories evolved to explain why such benefits accrue are diverse. The outstanding investigations indicate that there are at present two diametrically opposite conclusions derived from different techniques aimed in the same direction. On the one hand it is demonstrated that no appreciable change in residual stress results from peening except by a specific and unusual method and, on the other hand, it is stated as a result of comparable study that a generally accepted peening technique "will give plastic flow and full stress relief."

This sort of situation merely emphasises the fact that the effects of peening must be explored under conditions which will permit more accurate evaluation not only of those effects which more accurately reflect the most critical characteristics of the welded joint, but also of the variable characteristics of the pneumatic tools which are almost universally used for peening. Accordingly the American Bureau of Shipping proposed to the Welding Research Council that a welding-peening project be sponsored along substantially the following lines.

(1) Furnish scientific data as to the correctness of code requirements relative to the elimination of the peening of the first and last layers.
(2) Information as to the variables of peening which might be used by codes as a matter of control.
(3) Effect of peening on transition temperature of weld metal and the welded joint as a whole.

Within the scope of these objectives and by using automatically controlled welding and peening operations, it was proposed that the following principal variables should be explored:

(a) Size (weight) of hammer; (b) Adjustment (stroke frequency) of air pressure; (c) Temperature (time) at which peening is applied; (d) All variables, (a), (b) and (c) to be explored under two peening conditions, viz:

(1) Peening all but first and last or the both outside layers of weld deposits.
(2) Peening only the outside layers of weld deposits.

In order to carry out the objectives properly, the project was planned in three major phases: (1) the development of equipment and instrumentation; (2) the calibration; and (3) the making and testing of samples. The purpose of the present paper is to describe the work carried out under: (1) and (2), and in presenting the data derived from the calibration work to indicate the factors which appear to contradict some previous findings and certainly to differ from certain preconceived ideas regarding the characteristics of pneumatic tool performance. The results thus far obtained seem to indicate that the application of peening to welded joints should be fully explored, perhaps even beyond the scope which has been envisaged.

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NEWS OF THE MONTH

PERSONAL

Mr. R. G. W. Andrews has been appointed production manager of Venner Time Switches, Ltd. **Mr. W. J. Ryan** has been appointed deputy production manager and **Mr. R. A. Abbott** personnel manager of the firm.

Mr. J. S. Brough, who has been appointed manager of engineering to Monsanto Chemicals Ltd., has been acting as assistant manager of engineering since January 1st last. **Mr. W. M. Cooper,** who has been manager of engineering since 1946, becomes assistant to the managing director, to advise generally on engineering problems and to handle external engineering works.

Mr. S. Camm, C.B.E., F.R.Ae.S., Mr. G. R. Edwards, M.B.E., B.Sc., F.R.Ae.S., and **Major F. B. Halford, C.B.E., F.R.Ae.S.,** have been elected vice-presidents of the Royal Aeronautical Society.

Sir Alexander McColl has retired from the Board of the Vacuum Oil Company Ltd., Caxton House, Westminster, London, S.W.1, after 45 years of service with the company. The vacancy on the board has been filled by the election of **Mr. J. Blake Middleton,** who will take charge of the manufacturing department and be responsible for the design, construction and initial operation of the company's projected new refinery at Coryton.

Mr. C. H. M. Holden, managing director of the Hall Street Metal Rolling Co., Ltd., has been elected president of Birmingham Metallurgical Society.

Mr. P. Hopkinson, managing director of British Furnaces Ltd., Chesterfield, which is associated with the Surface Combustion Corporation, Toledo, Ohio, has returned home after a six weeks' business trip to America.

Mr. E. T. Judge, a director of Dorman, Long and Co., Ltd., has retired from the chairmanship of the Plant Engineering Panel of the British Iron and Steel Research Association. He is succeeded by **Mr. J. F. R. Jones,** chief constructional engineer with John Summers and Sons, Ltd.

Mr. T. Moore has been appointed to the power plant department of Simon-Carves, Ltd., Cheadle Heath, Stockport, as assistant sales manager for the northern area of the British Isles.

Aluminium Wire and Cable Company, Ltd., have announced that **Mr. W. J. Nicholls, B.Sc., M.I.C.E., A.M.I.E.E.,** has joined their staff on 1st June as Assistant to the Chief Electrical Engineer.

Mr. C. Pinkham, Manager of the Publicity Organisation of The General Electric Co., Ltd., is retiring on June 30th after serving for 37 years with the Company.

Mr. T. H. Redfern, chairman and managing director of Redfern's Rubber Works, Ltd., Hyde, Cheshire, has been elected President of the Federation of British Rubber Manufacturers' Associations for the year 1950-51, in succession to **Mr. G. E. Beharrell,** deputy-chairman and managing director of the Dunlop Rubber Co., Ltd.

The Minister of Supply has appointed **Sir William A. Stanier, F.R.S.,** as chairman of the board of directors of Power Jets (Research & Development) Ltd. He has been a director of Power Jets since 1944.

Mr. W. R. Stevens, B.Sc., M.I.E.E., of the Research Laboratories, General Electric Co., Ltd., Magnet House, Kingsway, London, W.C.2, has been elected vice-president of the Illuminating Engineering Society for the second year.

Richard Sutcliffe, Ltd., Horbury, Wakefield, states that, following the recent death of **Mr. T. D. Sutcliffe, Mr. W. F. G. Sutcliffe** has been appointed joint managing director and **Mr. J. D. Sutcliffe** sales director.

Mr. J. E. Swindlehurst, M.A., M.I.C.E., has been elected President of the Institution of Structural Engineers.

BUSINESS NOTES

British Insulated Callender's Cables Ltd., has recently exported a large consignment of power capacitors to Canada. The capacitors will be installed in the system of the Shawinigan Water and Power Company, Quebec Province. The complete order consisted of a 15,000 kVAr bank of capacitors for operation at 11 kV, made up of sixty 250 kVAr units.

The new premises opened by the **Selson Machine Tool Co., Ltd.,** at Cunard Works, Chase Road, N.W.10, on May 24th include not only spacious accommodation for the complete staff of the Company, but also a large well-lit showroom, which permits clear inspection of the many types of machine tools.

The British Thomson-Houston Co., Ltd., Rugby, is to supply four 44,400 kVA, 11,000-volt Alternating Current Generators of the vertical type, to the State Hydro-Electric Dept., Wellington, New Zealand, for the new Roxburgh Power Station in the South Island.

Elliott Brothers (London) Ltd. announce that arrangements have recently been concluded with the **Fisher Governor Company,** of Marshalltown, Iowa, U.S.A., for the manufacture in England of the full range of Fisher automatic control specialities. A new English company, **Fisher Governor Company Ltd.,** with registered offices at Century Works, Lewisham, London, S.E.13, has been formed to market Fisher products in Great Britain, Europe, and the British Commonwealth (except Canada).

Rapid Magnetic Machines Ltd., Birmingham, announce that their Permanent and Electro Separating Equipment and Lifting Magnets will now be handled in Scotland by their recently appointed Agents **John S. Young and Co., Ltd.,** 257-261 Eglington Street, Glasgow, C.5.

The address of the Manchester office of the **Brush Electrical Engineering Co., Ltd.,** has been changed to Victoria Buildings, 32, Deansgate, Manchester, 3.

Dowty Equipment Ltd., have made an agreement with **Rubber and Plastics Inc.,** of Dayton, Ohio, to manufacture Dowty Bonded Seals in the U.S.A. These seals, now used by over 500 manufacturing companies in this country, consist of a specially shaped rubber washer bonded to a metal ring which forms a leak-proof seal when compressed in a joint, withstanding pressures up to 10,000 psi.

A. A. Jones & Shipman Ltd., Leicester, England, wish to announce that they have become sole selling Agents for this country for the complete range of products, manufactured by the **Micromatic Hone Corporation,** Detroit, U.S.A.

This is an interim arrangement and will shortly be superseded by an agreement to manufacture the complete range of products in this country. The programme covers the production, sale and service of the patented Micro-Mold abrasive honing sticks, the full range of honing tools, and certain of the high production homing machines, complete with automatic sizing.

THE INSTITUTION OF HEATING AND VENTILATING ENGINEERS RESEARCH FELLOWSHIP.

In accordance with the announcement made by the retiring President of the Institution at the Annual General Meeting in February of this year, to the effect that the Council had decided to devote a portion of the Research Fund to the collation of existing data and the preparation of a report or reports in a form suitable for use by the industry, it has been decided to offer a Research Fellowship of £350 for one year. The Fellowship may be increased in amount and duration depending on circumstances.

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OBITUARY.

It is with deep regret that we record the death of Mr. W. D. Reid on May 21st, 1950, at the age of 87 years.

Prior to his retirement from the former Callender's Cable and Construction Co., Ltd., in 1942, Mr. Reid was for many years the Company's Chief Engineer for Scotland. His service with Callender's dated from 1888 and totalled 54 years, during which time he was closely associated with many important electrical engineering projects.

Subsequent to his retirement from Callender's, Mr. Reid became Technical Director of the Skelmorlie Electric Supply Company Ltd., in Scotland, and held that position until his retirement from business in 1948.

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY.

A Productivity Team from the Non-Ferrous Metals Industry left for New York on June 9th, to study the methods of production and the productivity of the non-ferrous metals industry of the United States. The Team is led by Mr. W. F. Brazener, managing director of The Mint Birmingham Ltd. The Team of 17 is drawn from all grades of the industry: management, technicians and craftsmen. It will be particularly interested to see new types of plant which have been developed in America during the last few years, and will be ready to answer enquiries concerning methods and processes which are current practices in the United Kingdom.

AN EXHIBITION OF ELECTRONIC FLASH PHOTOGRAPHY.

The outstanding advances which have been made in the field of electronic flash photography during recent years are revealed in a special exhibition which opened on 7th June at the Holborn Gallery of Ilford Ltd., 101, High Holborn, London, W.C.1.

This exhibition, which has been organised by Ilford Ltd. in collaboration with Mullard Electronic Products Ltd., will remain open to the public for about six weeks.

A large selection of photographs illustrates the manner in which electronic flash tubes are now being used in various branches of science, medicine and industry. Of particular interest are pictures illustrating the vital importance of electronic flash tubes in such varied research investigations as the atomisation of fuel in gas-turbine engines, the cavitation of ships' propellers, the break-up of water droplets, and the flow of gases in steel furnaces.

MOBILE DISPLAY VAN.

The Technical Press was recently invited to attend a demonstration of a new type of Mobile Display Unit which the British Oxygen Company has built for exhibiting its products at agricultural shows, etc., all over Britain. This van can be converted into an exhibition stand in only two hours. While this was being done, correspondents were shown films, and practical welding demonstrations of the latest welding and flame cutting methods given.

BRITISH DESIGNERS AND TEST PILOTS HONOURED.

The outstanding achievements in aeronautics by leading figures in the aircraft industry have been recognised by the Royal Aeronautical Society. Among those honoured by the Society are designers of gas-turbine engines and two test pilots.

The British Gold Medal for outstanding practical achievement leading to advancement in aeronautics has gone to an engine designer, Major F. B. Halford, now Chairman and Technical Director of the De Havilland Engine Company, Ltd. The highest honour which the Society can confer for work of an outstanding nature in aeronautics was awarded to Sir Geoffrey de Havilland. This is the Society's Gold Medal. The Society's Silver Medal has been awarded to two other aircraft designers. One is W. E. Petter, designer of Westland aircraft, and the other is J. Smith of Vickers-Armstrongs. The Society's Bronze Medal has been awarded to A. C. Lovesey, Chief Designer (Development) of Rolls-Royce Ltd. Two test pilots, P. W. S. Bulman of Hawker Aircraft and Captain J. Summers of Vickers-Armstrongs, have been awarded the British Silver Medal for Practical Achievement in Aeronautics.

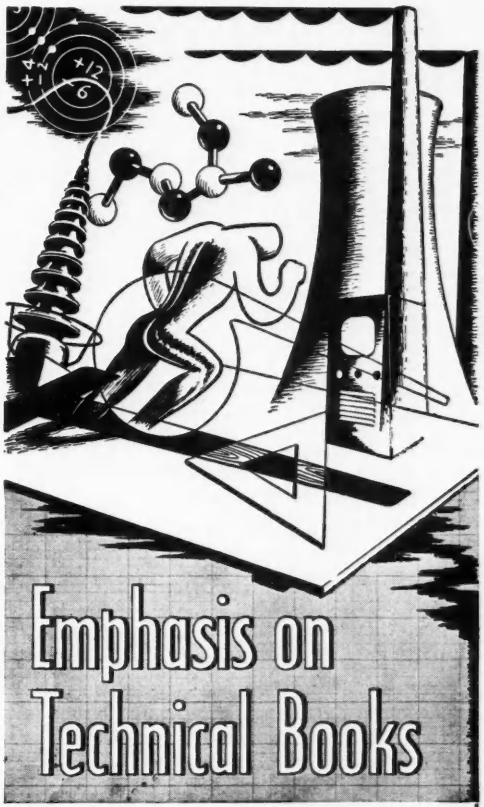
BRITISH STANDARDS

(Copies of British Standards may be obtained from the British Standards Institution, 24 Victoria Street, London, S.W.1.)

Lubricating Nipples for Aircraft Purposes, B.S. SP. 21 : 1950, deals with the material, dimensions and finish of light alloy miniature lubricating nipples for aircraft use. Price 1/-.

Cotton Selvedge Tapes and Webbing for Electrical Purposes, B.S. 633 : 1950, covers five classes of unsized cotton selvedged tapes and webbing, but tapes and webbing used for the manufacture and jointing of cables are not included. It gives full details of standard widths, number of ends, number of picks, thickness and tensile strength of the tapes and webbings, and methods of test are given in the Appendices. Price 2/-.

Vernier Callipers, B.S. 887 : 1950, relates to vernier callipers with internal and external measuring faces. First issued in 1940, it forms one of a series of standards for engineers' precision tools. It incorporates certain small modifications shown to be desirable as a result of experience of working to the previous standard and makes provision for a fuller range of graduations for scales on beams and verniers. The various types of graduation are illustrated and the possible combinations of beam and vernier scales are tabu-



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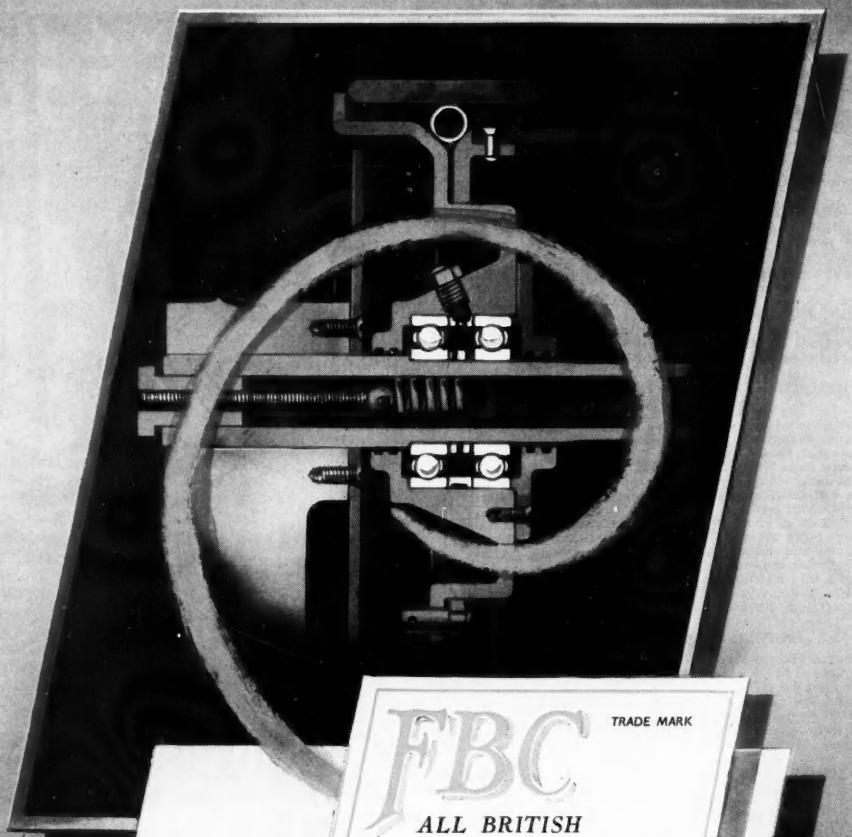

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'ated. Suggested dimensions for sections of beams and notes on methods of testing vernier callipers are given in Appendices. Price 2/6.

Report on the Selection of Ranges of Types and Sizes (Preferred Numbers), B.S. 1638 : 1950, shows that consumers' requirements are frequently satisfied with a range of sizes or capacities constituting a geometric series in which each size or capacity is a uniform percentage larger than its predecessor. The word "capacity" is used in its widest sense and covers all manner of characteristics, such as area, volume, weight, power, rating and so on. "Preferred number" series are tabulated, and their selection, properties and use are fully discussed. Illustrations are included, showing the simple arithmetical sequence of the logarithms of the preferred numbers, and how readily the series themselves can be built up and recognized by the use of logarithmically ruled graph sheets. Price 3/-.

Cast Iron Pipe Fittings for Sprinklers and other Fire Protection Installations, B.S. 1641 : 1950, deals with all types of cast iron fittings commonly used for automatic sprinkler installations. The fittings have taper threads conforming to the appropriate requirements of B.S. 21 "Pipe Threads, Part 1," with the exception of the minimum lengths of thread which are quoted in a table. The fittings covered are, in general, suitable for working water pressures up to 200 psi, and tests for porosity are included. Price 2/6.

Vernier Height Gauges, B.S. 1643 : 1950, is a new addition to the series of standards for engineers' precision tools. It deals with vernier height gauges having ranges of measurement, in inch units up to 48 in and metric units up to 1 metre. Essential features of design are specified and requirements are included for material and accuracy. Various types of scale graduation for beams and verniers are illustrated and the possible combinations of beam and vernier scales are tabulated. Price 2/6.

Industrial Safety Gloves, B.S. 1651 : 1950, deals with safety gloves, mittens and hand-guards for protection against common hazards in all industries. The gloves fall into five groups : leather, plastics, rubber, felt, and cotton. The standard includes a list of hazards and recommends the appropriate types of gloves for each hazard. Requirements are given for materials, sizes, manufactures and methods of test ; recommendations on the storage and preservation of rubber gloves are included, and a note on the information to be given when ordering gloves. Price 4s.

The Annual General Meeting of the British Standards Institution will be held on Tuesday, 11th July, 1950, at 3 p.m. in the Council Room of the Institution at 24, Victoria Street, London, S.W.1.

NEW ARRANGEMENTS FOR STEEL DISTRIBUTION

Under an Order signed by the Minister of Supply, arrangements are made for collecting, with little inconvenience, statistics of deliveries of steel to the main consuming industries and for export.

This is necessary because of the ending of distribution control for general steel, announced by the Minister on May 22nd.

Small purchases not exceeding 5 lb per month, and sheet steel, tinplate, ternplate and blackplate are excluded from the conditions of the Order.

The Order—the Iron and Steel Utilization (Records) Order, 1950 (S.I. 1950, No. 873)—came into operation on June 4th, and copies are now available from H.M. Stationery Office.

HOOVER MOTORS IN MECHANICAL HANDLING

New Hoover fractional horsepower electric motors, which were shown at the Mechanical Handling Exhibition, are being used in Hoover's Cambuslang factory for operating conveyor systems in plating, paint and impregnating shops, etc. It is also noteworthy that in this highly modern factory, where these motors are produced, the latest mechanical handling equipment is everywhere in evidence, examples ranging from fork lift trucks to automatic turn-tables, besides advanced conveyorised methods throughout the production system.

BOOKS RECEIVED

1899-1949. By John Dummelow, M.A., A.M.I.E.E. Publishers : Percy Lund, Humphries & Co., Ltd., Bradford. 250 pp.

This book has been issued by the Directors of the Metropolitan-Vickers Electrical Company to thousands of home and export customers to commemorate the Golden Jubilee of this concern. It covers outstanding events and personalities during the period 1899-1949, the material having, to a large extent, been contributed by past and present servants of the Company. It is profusely illustrated and constitutes a lasting record of their achievements in all fields over the past 50 years.

Drop Forging. By Henry Hayes. 105 pp. Price 6/-. Publishers : Sir Isaac Pitman & Sons, Ltd.

National Certificate Workshop Technology. By T. Nuttall, A.M.I.Mech.E., A.M.I.P.E. 260 pp. Price 8/6. Publishers : The English Universities Press Ltd.

Jig and Fixture Design. By H. W. Hardy, A.M.I.Mech.E. 64 pp. Price 12/6. Publishers : Sir Isaac Pitman & Sons, Ltd.

Rubber in Aircraft. By T. L. Garner, M.Sc., D.L.C., A.R.I.C., A.M.I.Chem.E., A.F.R.Ae.Soc., F.I.R.I., and J. F. Powell, M.A., A.R.I.C. 72 pp. Copies of this publication may be obtained, free of charge, on application to The British Rubber Development Board, Market Buildings, Mark Lane, E.C.3.

LETTER TO THE EDITOR

DEAR SIR, In your March, 1950, issue, page 92, an article describing "A New Frequency Meter and its Applications" appeared. We would like to point out that the principle described has been known to many manufacturers for a considerable period and certain aspects of the design have been used for many years. For instance, at least two British manufacturers, Messrs. Evershed and Vignoles Ltd., and ourselves, used a cross-coil type frequency meter before 1937. A particular example is the illuminated speed meter fitted on certain underground rolling stock, which is, in effect, a frequency meter. This instrument indicates the frequency of a generator which forms part of one of the wheels on the vehicle.

Yours faithfully,

W. BAMFORD,
Director of Sales,
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We hope that it will be appreciated that it is physically impossible for anyone to have full information on all previous developments in the various engineering fields. It therefore happens from time to time that our journal publishes an article in which a device which has concurrently, or even previously, been developed in another country is claimed by the author to be a new one. We trust, however, that apart from the author's claim that the frequency meter was a new type, our article was nevertheless interesting in view of the fact that it gave detailed information on the working principle of the meter circuit.—EDITOR.

Classified Advertisements.

The rate for all classified advertisements is 6d. per word ; in bold print 9d. per word ; minimum order 6s. Box number advertisements 1s. extra. Instructions together with remittance must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

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WANTED

BACK ISSUES OF THE ENGINEERS' DIGEST Wanted. Double the original price, 9/- per copy offered for copies of the August, 1940, issue.—Send copies to the SUBSCRIPTION DEPARTMENT, "THE ENGINEERS' DIGEST," 120 Wigmore Street, London, W.1.

WORK WANTED

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